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	Engineering and Design LOCK GATES AND OPERATING EQUIPMENT	
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ENGINEERING AND DESIGN

Lock Gates and Operating Equipment

ENGINEER MANUAL

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Engineering and Design
LOCK GATES AND OPERATING EQUIPMENT

1. Purpose. This manual provides guidance in the structural, mechanical, and electrical design of lock gates and operating equipment at navigation projects.

2. Applicability. This manual applies to all HQUSACE elements, major subordinate commands, districts, laboratories, and field operating activities having responsibilities for the design and construction of civil works projects.

FOR THE COMMANDER:

WILLIAM D. BROWN
Colonel, Corps of Engineers
Chief of Staff

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This manual supersedes EM 1110-2-2703, dated 29 February 1984.

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Chapter 1
Introduction

1-1. Purpose

This manual provides guidance in the structural, mechanical, and electrical design of lock gates and operating equipment at navigation projects.

1-2. Applicability

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1-3. References

References are listed in Appendix A.

1-4. Applicable Computer Programs

CMITER, Computer Aided Structural Engineering, U.S. Army Engineer Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199.

1-5. Plates

Illustrative plates containing general information, typical details, mechanical design data, and sample computations are included in Appendix B, and are referred to herein as Plate B-1, B-2, etc.

1-6. General

a. *Function of gates.* Lock gates serve a number of different functions, depending on location and conditions. While the major use of lock gates is to form the damming surface across the lock chamber, they may also serve as guard gates, for filling and emptying the lock chamber, for passing ice and debris, to unwater the lock chamber, and to provide access from one lock wall to the other by means of walkways or bridgeways installed on top of the gates. A navigation lock requires closure gates at both ends of the lock so that the water level in the lock chamber can be varied to coincide with the upper and lower approach channels. The sequence of "locking" a vessel upstream is: first, lower the water level in the lock to the downstream water level; second, open the lower gate and move the vessel into the lock chamber; third, close the lower gate and fill the lock chamber to the level of the upper pool; and finally, open the

upstream gate and move the vessel out of the lock. Lockage of a vessel downstream involves a similar sequence in reverse order.

b. *Types of gates covered.*

(1) Miter gates. A very large percentage of the locks in the United States are equipped with double-leaf miter gates which are used for moderate- and high-lift locks. These gates are fairly simple in construction and operation and can be opened or closed more rapidly than any other type of gate. Maintenance costs generally are low. A disadvantage of this gate is that it cannot be used to close off flow in an emergency situation with an appreciable unbalanced head.

(a) Miter gates fit into recesses in the wall in the open position. The bottom of the recess should extend below the gate bottom to preclude operating difficulties from silt and debris collection. Enlarged recesses are sometimes used to facilitate the removal of accumulated ice. An air bubbler system is recommended to help clear ice and debris from gate recesses. (See Appendix D for typical air bubbler recess flusher.)

(b) Miter gates are framed either horizontally or vertically. The skin plate of a horizontally framed gate is supported by horizontal members which may be either straight girders acting as beams, or circular arches. Each such horizontal member is supported by the vertical quoin post at one end and the miter post at the other. All water load is transmitted through the girders and quoin blocking into the gate monoliths. A vertically framed gate resists the water pressure by a series of vertical girders more or less uniformly spaced throughout the length of the gate, and supported at top and bottom by horizontal girders transmitting the loads to miter and quoin at the top of the leaf, and directly to the sill at the bottom.

(c) The relative costs of the two types of gates (horizontally and vertically framed) depend largely upon three main factors:

- Overall weight of the gate;

- Simplicity of design and ease of fabrication and erection;

- Cost of that part of the lock walls and sills influenced by the design of the gates.

(d) When the ratio of the height of a leaf to its width is greater than about 0.7, the horizontally framed gate will weigh less. For long, shallow gates, vertical framing requires less material.

(e) The overturning moment carried to the lock wall by a horizontally framed gate is greater about all points below the sill than that caused by a vertically framed gate, unless the entire sill load is transmitted to the wall. Hence, the latter type requires less masonry in a thrust wall of gravity section, but the heavier sill necessary to support the bottom girder into which the verticals are framed may counterbalance this saving.

(f) Due to the greater rigidity and resistance to boat impact of the horizontally framed gate and the insignificant difference in cost, the vertically framed gate will no longer be used except for unusual applications and upon special approval.

(2) Sector gates. A sector gate is similar in shape to a tainter gate except it is oriented to rotate about a vertical axis and is supported at the top and bottom in a manner similar to a miter gate. Like miter gates, sector gates are used in pairs, meeting at the center of the lock when in the closed position and swinging into recesses in the lock walls for the open position. The trunnions are located in the lock walls, and the skin plates face in the direction of the normally higher pool level.

(a) Sector gates are used at both ends of locks that are located in tidal reaches of rivers or canals where the lifts are low and where the gates may be subjected to reversal of heads. Since these gates can be opened and closed under head, they can be used to close off flow in an emergency. The gates swing apart and water flows into or out of the lock through the center opening between the gates. In some cases, flow is admitted through culverts to improve filling characteristics or where ice or drift may not permit adequate flow between the gates.

(b) Because the turbulence area at the upper end of a lock filled by a sector gate is not effective for lockage of vessels, the length of the lock chambers must be increased proportionately. Model tests indicate that about 100 feet (ft) of additional length is required. Like other end-filling systems, sector gates cannot be used for filling and emptying high-lift locks unless the filling and emptying rates are greatly reduced. The practical lift limitation is usually about 10 ft, although gates with higher lifts have been built.

(c) The disadvantages of the sector gates are high construction cost, long opening and closing times, and larger wall recesses.

(3) Vertical-lift gates. Vertical-lift gates may be used at both ends of a lock, or at only one end in combination with a miter gate at the other end. They can be raised or lowered under low to moderate heads but are not used when there is reversed head. Their operation time is much slower for older gates and maintenance costs are higher than those of miter gates, but they can be used in emergency closure. The newer gates, however, are capable of achieving operating speeds equal to, or even faster than, miter gates.

(a) A vertical-lift gate installation at the upstream end of a lock normally consists of a single-leaf submergible gate, which rises vertically to close off the lock chamber from the upper pool. When the lock is filled, the gate is opened by sliding the leaf vertically downward until the top of the leaf is at or below the top of the upper sill.

(b) In some cases, a double-leaf vertical-lift gate may be used. The upper leaf can be provided with a curved crest which permits overflow to supplement flow from the primary filling system when the lock chamber is nearly full. This type of gate can also be used for skimming ice and debris.

(c) When a vertical-lift gate is used at the downstream end of a lock, it is raised vertically to a height above the lower pool level so that vessels can pass underneath. The gate leaf is suspended from towers on the lock walls and may be equipped with counterweights to reduce the power hoist size. Lock gates of this type are practical only for very high locks and where required vertical clearance can be provided under the gate in its raised position.

(4) Submergible tainter gates. The locks of the Dalles Dam, some Lower Snake River projects, and the Upper and Lower St. Anthony Falls Locks have submergible tainter gates. This type of gate is raised to close the lock chamber and lowered into the lock chamber to open it. The end frames are recessed into the lock wall so no part of the end frame projects into the passageway. This type of gate was chosen because it is structurally efficient and was estimated to be lighter in weight and less costly than a double-leaf miter gate for these applications. Also, the tainter gate permitted the length of the approach channel to be reduced by the leaf

width of the miter gate. There are two potential problem areas in the operation of this type of gate: skewing of gate during opening and closing, and vulnerability to damage if hit by lock traffic. However, with good design practices and lock management, these problems will be minimal.

1-7. Materials and Working Stresses

a. Materials. This manual serves only as a guide and the following list should not be considered as a complete listing of materials that may be used.

(1) Structural steel. Lock gates are usually constructed of structural grade carbon steel having a yield point of 36,000 pounds per square inch (psi). Low-alloy steel, with a yield point up to 50,000 psi, is quite frequently used as skin plate in conjunction with structural grade girders. In some cases for the larger gates, other than miter gates, low-alloy steel may be economical for the complete gate. The deflection of members fabricated of high-strength low-alloy steel should always be investigated as it will always be more severe than if the members were of structural grade carbon steel. For miter gates, structural grade carbon steel should be used regardless of the gate height in the interest of providing a more rigid gate, except for the skin plate and diagonals which may be of high-strength, low-alloy steel whenever warranted.

(2) Corrosion-resistant steel. Corrosion-resistant steel normally should only be used in locations where corrosion is expected to be severe or where corrosion will impair the normal efficiency of gate operation. Under most conditions, seal contact surfaces of lock gates are not required to be corrosion resistant but under adverse conditions corrosion-resistant clad or solid stainless steel plates may be desirable. For some lock locations and conditions it may also be desirable to clad the contact surfaces of miter and quoin blocks with corrosion-resistant steel or to use solid stainless or corrosion-resistant steel miter and quoin contact blocks. Flame spraying of corrosion-resisting steel particles to surfaces subject to severe corrosion may be advantageous where using solid or clad corrosion-resisting steel is not practical or not economical. The new guide specification CW-05036 covers the requirements for surface preparation and applications of metalizing/flame spraying coatings.

(3) Cast steel. The operating strut pin bearing collars, pintle sockets, and pintle shoes are normally fabricated of cast steel, utilizing mild-strength to medium-strength carbon steel castings. For items that are subjected to higher stresses than medium-strength castings are capable of carrying, such as the miter guide roller and pintle balls, high-strength, low-alloy steel castings should be used.

(4) Forged steels. Gudgeon pins, operating strut connecting pins, anchor link pins, parts of the anchorage links, and guide roller pins should be made of carbon steel forgings rated for general industrial use. Forgings may be untreated or heat-treated depending on intended use and requirements. The pintle ball of most gates is made of an alloy steel forging containing nickel, giving the forging a good allowable bearing value as well as a fair degree of corrosion resistance. Corrosion-resistant weld overlays may also be used on pintle balls in highly corrosive environments.

(5) Bronze. Bushings for all lock gate components are normally made of bronze. Usually bearings are made of a bronze designated for general purpose applications. Where stresses are encountered that are higher than desirable for the general purpose bronze, aluminum bronze may be used.

(6) Bolts. Where bolted connections are used for parts of the gate that may have to be removed for maintenance or repair, a copper-nickel alloy, usually referred to as monel, or an equally corrosion-resistant steel should be considered, especially if corrosive elements are present. The 300 series stainless steel and bronze bolts, nuts, washers, and setscrews have been used with good results in highly corrosive environments. Ordinarily, bolts, nuts, and washers should all be made from the same type of material; however, if salvage and reuse is intended different alloy combinations for bolts and nuts should be used to minimize seizing. Normal applications of this type of connection are pintle socket to gate connection, quoin and miter water seal bolts, and bolts for the bottom seal. Where bolts are used and corrosion is not a factor, ASTM A307 or A325 bolts should be used, with bolt strength dictated by load and conditions.

(7) Fabrication. Fabrication of all lock gates should be by welding, with bolts being used only for those parts that may have to be removed for maintenance or repair. The application of welding generally results in lighter and stronger gates. All welding should be done in accordance with the current Structural Welding Code of the American Welding Society, Section 9, Design of New Bridges.

b. Design strength. Structural steel gate members shall be designed in accordance with the requirements of EM 1110-2-2105. For general purpose bronze bushings, the allowable bearing should be below 1,500 psi with a maximum concentrated bearing of not more than 5,000 psi (this refers to a bushing with an eccentric load). Where a higher allowable bearing is desirable, aluminum bronze may be used with working stresses up to 5,000 psi and a concentrated bearing of not more than 10,000 psi as described above. Working stresses for both forgings and castings should be based on yield strength and for normal applications should be no more than $0.50F_y$.

1-8. Basic Dimensions

a. Miter gates. A miter gate is a three-hinged arch when the leaves are mitered. Gate geometry is a function of the angle the work line of the leaf makes with a line normal to the lock walls, with the gate in a mitered position. Past study and design have determined that for miter gates a slope of 1L on 3T gives the best results (L = longitudinal, T = transverse). In general, vertically framed gates have been used where the height-to-length ratio of the leaf was less than 0.5. The approximate ratio of height to length, where the weight of a vertically framed leaf is essentially the same as a horizontally framed leaf, is somewhere between 0.70 and 1.0 (see paragraph 1-6b(1)). However, vertically framed gates are not recommended for new construction. Even with a slight increase in cost, the greater rigidity of the horizontally framed gates makes them more desirable.

(1) The pintle is located so that the leaf, when recessed, is completely within the lock wall and so that the pintle is eccentric (upstream) with respect to the center of curvature of the bearing face of the quoin contact block. The center of curvature of the bearing face is always located on the line tangent to the thrust line at the quoin contact point. The pintle eccentricity, which makes the quoin block approach the contact point tangentially, should be approximately 7 in., thereby reducing the possibility of metal interference (see paragraph 2-1h).

(2) The arch-type miter gate is a horizontally framed structural system of curved members with a composite acting skin plate. Except for the curvature, the gate size and other components are similar to or the same as horizontally framed straight gates.

b. Sector gates. Sector gates are generally laid out with the frames forming an equilateral triangle. The normal layout is for 60 degrees (deg) or greater interior angles, formed by the frames and a chord line behind the skin plates. One strut is parallel to the lock wall in the closed position, thereby causing the other strut to form an angle equal to the interior angle, with the lock wall. The pintle is located so that the gate is completely in the recess in the open position.

c. Vertical-lift gates. Dimensions for vertical-lift gates are based solely on lock width and girder depths required by the head. Recesses in lock walls for upper gates are determined by load, girder depth, and detail requirements. Towers for downstream gates are also determined by load, counterweights, and related details.

d. Submergible tainter gates. As with spillway tainter gates, the controlling dimensions are the lock width, gate radius, and end frame and trunnion hub location. Plates B-45 and B-46 show typical end frame and cross section of the gate.

1-9. Loads

The loads applicable to lock gate design are dead, hydrostatic, hydraulic, temporal, and boat impact. Miter gates are also subject to torsion. Dead load is the weight of the structure plus mud and ice; hydrostatic load is the water load on the gate produced by the pool differential; boat impact is the dynamic force applied to the gate by the barge impact; temporal load is the water surge forces from wave loads or overfilling of the lock; and torsion on miter gates is the result of a twisting action from the operating strut force and the water resistance caused by the leaf moving. For more specific lock gate loads, see the gate type's respective section herein.

a. The controlled upper and lower pools cause the normal loading, and greater water forces, such as unwatering the lock, are considered emergency conditions, with an increase in allowable stress of 33 percent.

b. The force of impact usually is limited by local failure in the region of impact. For design purposes, this force, supported by past designs, is converted into an equivalent water load of 10- to 15-ft head below the top girder and of 6- to 10-ft head above the top girder for vertical-lift gates if horizontally framed. An impact load of 250,000 or 400,000 pounds (lb), according to location of load, is applied above the pool to horizontally framed miter gates. (See paragraph 2-1b(1)(d).) Barge or impact force is generally not applied to vertical framing members. Greater impact forces or the use of barriers may be justified based on the importance of the waterway or type of traffic.

c. On sector gates a design withstanding a concentrated impact force of 125,000 lb applied to the top horizontal girder is recommended, with vertical framing members designed for no impact loading.

d. The quoin end of a miter gate leaf is held vertical by the pintle and gudgeon pin, leaving the miter end free to twist out of vertical alignment. The deadweight of the leaf, along with ice or mud, also causes the leaf to twist. To keep the leaf in vertical alignment while stationary, and to eliminate excessive deflection during operation, diagonals are provided on the downstream faces of horizontally framed miter gates and on both upstream and downstream faces of vertically framed miter gates. These diagonals act as tension members for all normal gate operations. (See USAED, Chicago 1960.)

1-10. Fatigue and Fracture Control

All possible modes of failure should be considered when designing lock gates. Possible failure modes are: 1) general yielding or excessive plastic deformation, 2) buckling or general instability, 3) subcritical crack growth leading to loss of cross section or unstable crack growth, and 4) unstable crack extension leading to failure of a member. Failure modes 1 and 2 are addressed by Load and Resistance Factor Design (LRFD) and Allowable Stress Design (ASD) principles whereas failure modes 3 (fatigue) and 4 (brittle fracture) can be addressed using fatigue and fracture mechanics principles. Welded construction with its emphasis on monolithic structural members has led to the increased desirability of including fracture criterion in addition to strength and buckling criteria when designing a structure. Stress range, detailing, and the number and frequency of load cycles control fatigue while geometry, toughness, and stress levels control fracture. For further guidance, see EM 1110-2-2105.

a. Fatigue requirements. Fatigue can be controlled by stress range, detailing, and the number and frequency of load cycles. While the number and frequency of load cycles are usually controlled by the structure's purpose, the designer can control the stress range and the choice of detail. Refer to AISC (Current Edition), Appendix K, for guidance in design and detailing.

b. Fracture control requirements. The designer should set limits on tensile stress levels, enforce controls on quality fabrication and inspection procedures to minimize initial defects and residual stresses, designate the appropriate temperature zone, and specify the related minimum fracture toughness for critical members and/or

components. For lock gates, fracture critical members shall be defined as "members and their associated connections subjected to tensile stresses and whose failure would cause the structure to be inoperable." For minimum Charpy V-notch impact test values see EM 1110-2-2105.

1-11. Operating Machinery General Design Criteria

a. Machinery components. All components of the gate operating or hoisting machinery except compression members which may fail by buckling should be designed for loads or forces produced by an effective cylinder operating pressure or normal full load torque of an electric motor with a minimum safety factor of five based on the ultimate tensile strength of the material involved. In addition, each part or component should be designed for a unit stress not to exceed 75 percent of the yield strength of the material for the maximum load, maximum cylinder pressure obtainable, or overload torque from an electric motor.

b. Piston rods. Piston rods and other compression members in which failure may be caused by buckling should be designed in accordance with either the Johnson or Euler equation, whichever applies. A factor of safety of at least 2.5 should be provided based on the maximum load to be imposed on the member and the critical buckling load. In almost all cases the end fixity coefficient for pin-ended columns should be used.

c. Shafting. Shafting should be designed for the rated loads, increased by applicable shock and fatigue factors, with a factor of safety of five based upon the ultimate strength of the materials, provided the stresses produced by the maximum torque of the motor do not exceed 75 percent of the yield point of the materials involved. Stress concentration factors should be used where applicable. A combined shock and fatigue factor of 1.25 should be used. Shafting should be amply supported, and provided with adequate means to prevent longitudinal movement. The distance between bearings on shafting subject to bending, except that due to its own weight, should be such that the maximum shaft deflection will not exceed 0.01 in./ft of length at rated load. Torsional shaft deflection should not exceed 0.08 deg/ft of shaft length at rated load. If spur gears are mounted on the shafts it is necessary to limit the relative slope of the shafts containing the gear and pinion. It has generally been found acceptable to limit the slope of the shaft at the center line of the gear mesh to one-third the backlash divided by the gear face width. The usual range of

backlash for spur gears is 0.03/D.P. to 0.05/D.P. in., where D.P. is the diametral pitch.

d. Speed reducers. Speed reducers should be worm, helical, or herringbone type in accordance with the applicable American Gear Manufacturers Association (AGMA, Current Edition) standards with antifriction bearings. If possible, an oil meeting the requirements for the ambient temperatures that will be encountered should be used. Where ambient temperature range will exceed that recommended for the oil, a thermostatically controlled heater should be provided in the reducer case to keep the oil at the temperature recommended by the oil manufacturer. Where heaters are used, the surface area of the heater should be as large as possible to prevent charring of the oil. The watt density of elements selected should not exceed 10 watts per square inch. In the interest of energy conservation, consideration should be given to insulating the reducer case to minimize heat loss. Another alternative would be the use of a synthetic gear lubricant with a minus 40° Fahrenheit (F) pour point if acceptable to the reducer manufacturer. Reducer selection should be based on manufacturer's published ratings for the required service conditions.

e. Couplings. Flexible couplings should be of the gear type. Couplings should have flanged sleeve housings and integral lips at each end to house the seals and retain the sleeves. Selection normally should be based on manufacturer's published rating. Sleeves should be fastened so that they cannot work loose or slip off. Couplings with sleeves held in place with snap rings should not be permitted.

f. Brakes. Brakes should be of the shoe type, spring set, with D-C magnet operated release and should be completely enclosed in a watertight and dusttight enclosure. The brake should have a torque rating not less than 150 percent of the full load torque of the motor when referred to the shaft on which the brake wheel is mounted, efficiency not being considered. The torque rating should be based on continuous duty. Fuses should not be used in the brake control circuit.

g. Bearings.

(1) Antifriction bearings should be selected in accordance with manufacturer's published catalog ratings. Life expectancy should be based on 10,000 hours B-10 life with loads assumed equal to 75 percent of maximum.

(2) Bronze sleeve bearings should have allowable unit bearing pressures not exceeding the following:

(a) Sheave bushings, slow speed, Federal Specification QQ-C-390B, Alloy C90500, 3,500 psi.

(b) Main pinion shaft bearings and other slow-moving shafts, hardened steel on bronze Federal Specification QQ-C-390B, Alloy C90500, 1,000 psi.

(c) Bearings moving at ordinary speeds, steel or bronze Federal Specification QQ-C-390B, Alloy C93400, 750 psi.

h. Open gearing. Open gearing should have spur teeth of the involute form, to comply with AGMA 201.02, ANSI Standard System, "Tooth Proportions for Coarse-Pitch Involute Spur Gears" (Information Sheet A). Strength should be based on static load from the Lewis equation modified for pitch line velocity by the factor (600 + velocity in feet per minute (fpm)) divided by 600.

i. Efficiency. In computing losses in a lock-gate-operating machine the following should be used as a guide:

(1) Silent chain (includes oil-retaining and dust-tight case)	97%
(2) V-belt (includes both drive and driven sheave)	90-96%
(3) Spur gear reduction unit up to	
16:1 ratio	88%
16:1 to 40:1 ratio	84%
14:1 to 150:1 ratio	78%
(4) Herringbone gear reduction unit	
Single reduction	97%
Double reduction	95%
Triple reduction	90%
(5) Planetary or helical reduction unit	
Single reduction	97%
Double reduction	95%
Triple reduction	90%
(6) Pair of spur gears (Gears only)	97%
(7) Pair of bevel gears (Gears only)	95%
(8) Worm gear reduction unit	

Since worm gears are the most controversial class of all gearing, the manufacturers should furnish the certified starting and running efficiency of the unit, particularly if the unit is operated at other than standard speeds.

(9) Bearings

Ball and roller	98%
Intermediate horizontal shafts, bronze bushings	95%
Very slow speed shafts, bronze bushings	93%

j. Hydraulic systems and components.

(1) System types. Two basic types of lock hydraulic systems are currently in use. One is the central pumping unit type where the system pumps are all located in one central location with supply and return extending to the gate and valve operating machinery location on the lock. The other type consists of pumping unit assemblies complete with reservoir, valves, and necessary system components located at each individual operating cylinder, or at each of the four corners of the lock. A pumping unit at each corner could then operate a gate leaf and a tainter valve. If local pump systems are used at each operating cylinder, they could also be piped to a near valve or gate cylinder for backup hydraulic power.

(a) Central pumping system. Many of the central pumping systems of the past have used constant displacement screw pumps with system operating pressures of 900 psi to as high as 1,500 psi. Usually, three main supply pumps and one smaller capacity holding pump were used. The capacity of the main pumps was such that for normal operation two pumps would supply the required flow. Operation was alternated between the three pumps so as to equalize wear, while also maintaining standby capability. The smaller capacity pressure holding pump was used to build and maintain system pressure and allow the larger pumps to start unloaded and operate unloaded when the gates were not being moved. With this system, flow control and deceleration valves were used to control the speed of the valves or gates. Experience has shown this system to be simple, reliable, and fairly economical. In recent years variable displacement piston pumps have been used with the central pumping system. Pumps with three to five preset delivery positions have been used, with one position set at zero delivery so that the pumps can start or idle unloaded. Systems using these pumps rely on the preset variable displacement to control valve and gate speeds. With these types of pumps, two pumps are required for

each lock so that each miter gate leaf cylinder can be supplied by one pump. With a double lock, the four required pumps provide adequate standby capacity through interconnecting valving. On a single lock a third standby pump should be considered; however, if economics or space requirements preclude installation of the third pump, the two pumps should be interconnected to provide standby operational capability at reduced speed, if one unit should malfunction. The variable displacement capability makes these pumps very well suited for controlling gate speed.

(b) Local pumping system. The local pumping system is usually used on locks that are not subject to flooding (overtopping); however, local pumping systems can be used with success on locks subject to inundation with special attention paid to lock design. Local hydraulic pumping units and controls should not be located in the galleries on locks which are subject to overtopping. Where galleries are used the galleries should be sealed with watertight doors; the piping should penetrate the walls through sealed sleeves; and a sump pump should be provided to handle any leakage incurred. Local pumping systems can utilize any of the conventional types of pumps, with operating pressures in the 2,000- to 3,000-psi range acceptable. Large system pressure drops and high system shock pressures are reduced by the absence of long hydraulic line runs. Variable displacement piston pumps may be best suited for this application due to their high pressure capabilities, efficiency, and variable flow capabilities.

(2) System operating pressure. Many factors must be considered in the selection of the system operating pressure. Among the most predominate of these factors are reliability, serviceability, efficiency, safety, and economics. Also among these factors are pump type, pressure rating and capacity, cylinder size and pressure rating, pipe size, friction loss, bursting pressure, and system shock. In Europe, operating pressures as high 5,000 psi have been used for several years on locks and dams with good success, whereas in the United States these pressures are still not as common with hydraulic equipment manufacturers. System operating pressures should be as follows:

(a) Central pumping system operating pressure of 900 psi to as high as 3,000 psi should be satisfactory.

(b) Local pumping system operating pressure of 1,500 psi to 3,000 psi should be satisfactory and desirable.

(3) System components. The manufacturer's published pressure rating should be used for the selection of all system components. All published ratings should be equal to twice the system's operating design pressure, thus establishing a high level of quality for the equipment.

(a) Cylinders. The types of hydraulic cylinders that have been used on locks in the past include the specially designed, the tie-rod type, and the mill type. Manufacturers' standard mill type is the preferred, as it is known as the extra heavy duty type. These, however, should be designed with a factor of safety of five based on the ultimate strength of the material involved. Tie rod cylinders have also been used with good success. Where specially designed cylinders are required, they may be constructed of seamless steel tubes on flat plates rolled into cylinders; forged in one piece with integral flanges; or centrifugally cast steel. Fittings for supply and return lines to hydraulic cylinders should be mounted on the top or sides of the cylinders. These connections should be for "SAE four-bolt flange" or "SAE straight thread O-ring" connections for installation and maintenance convenience. Cylinders should be fitted with air bleed vents and drains at each end of the cylinders. Another optional feature which may be beneficial under certain circumstances is the adjustable cushion which is used for deceleration control at stroke limits. Piston rods are usually chrome plated for wear resistance and may be high strength stainless steel where corrosion is a concern. Ceramic coated rods, which have been used for several years in Europe but are relatively new in the U.S., may be considered for corrosive and abrasive service. On cylinders that are foot mounted, wedges should be provided between cylinder feet and shear plates to assure a tight fit. Specifications should indicate that cylinders shall be shipped with piston rod retracted and restrained from movement. Cylinders should be filled with new hydraulic fluid (the same type as that specified for the system) after manufacture to prevent corrosion during the storage period prior to use. An accumulator charged to 100 psi connected to the rod end port to allow for fluid expansion and contraction is a good method to do this.

(b) Pumps. Several different types of pumps have been used in locks in the past; these include gear, vane, and piston (both axial and radial) pumps. The gear pump is simple in design, rugged, has a large capacity for a small size, is low in cost, and has a high tolerance for contaminants in hydraulic fluids. The gear pumps' low volumetric efficiency, high wear characteristics, noise, fixed volume, and relatively short life expectancy make them undesirable for main pressure pumps. Variable volume vane pumps are efficient and durable if a clean hydraulic system is maintained. They are generally quiet, but may whine at higher speeds, and they are compact in relation to their output. The piston-type pump is the one recommended for main hydraulic power, as it has the highest volumetric and overall efficiencies, is capable of high output pressures, readily lends itself to variable displacement, and generally has long life expectancy. In order to reduce noise and increase life expectancy the pump speed should be 900 to 1,800 rpm. A variable delivery radial piston type, three to five adjustable delivery rate pump with solenoid control for selection of pumping rates is a desirable pump for main hydraulic pressure supply. One of the delivery rates on the pump should be set at neutral or zero delivery so as to start the pump motor under a no-load condition. The individual controls on each pump should be adjustable from zero to full flow capacity at each control setting so that flow rates can be varied in the field to suit minor variations in operating conditions. The pump shall be equipped with an auxiliary gear pump for pilot pressure, internal pressure relief valves, and an adjustable flow control device to control the speed of shifting between pumping rates. Variable volume axial piston pumps with the swiveling barrel, rather than swashplate, have also been used with good success. These tend to be a higher grade pump with less noise, vibration, and wear than the swashplate design. If an axial piston pump is used, then an additional auxiliary pump will be required for pilot pressure.

(c) Directional control valves. The directional valves normally used are four-way, three-position, blocked center solenoid-controlled pilot operated, spring-centered type. Where the solenoid control is selected, the valve should be equipped with adjustable orifices to slow the action of the spool when changing spool positions. The edges of the valve spools should be grooved to provide a throttling effect when moving from one position to another. The tandem center-type spool has been used in the past; however, system diversity is limited by this type of valve. Lever-operated directional control valves have also been used in the past; but they will not lend themselves to interlock logic control, so they should be considered on only the most basic application. The directional control valve could be the single greatest pressure loss point in a hydraulic circuit and, therefore, should be given a great deal of design attention. If practical, the directional control valves should be designed for 1.5 to 2.0 times the maximum flow rate required in order to minimize pressure loss. There are several companies that manufacture high quality manifolds for mounting cartridge-type control valves. This

type of system can be used to mount directional control, relief valves, counterbalance valves, proportional valves, and other types of control valves. The manifold system is economical, minimizes pipe fabrication, possibility of leaks, and space requirements and, therefore, should be used wherever possible. The solenoid-control valve for the main directional control valve should be provided with manual operating pins for emergency operation during solenoid malfunction or failure.

(d) Relief valves. Relief valves that are normally used on pressure lines are the balanced piston type, internally operated with an adjustable operating range. These valves have been used with good success and have proven to be rugged and reliable. The manifold and cartridge valve system should be considered as it may prove to be advantageous because it offers space and cost savings and easy maintenance. The cartridge valves should be the pilot-operated poppet type with adjustable pressure relief range. Response times are very quick on cartridge valves, usually in the 10-millisecond range, so the designer must decide how much slower the poppet should respond to eliminate the operational shocks.

(e) Flow control valves. Flow control valves, if required, should be of the adjustable orifice type, allowing controlled flow in one direction, free flow in the other direction. Where inertia loads such as miter gates are being controlled by hydraulic cylinders, the flow control valve should be placed to control the oil leaving the cylinder. When used in conjunction with a counterbalance valve, or in an element moving vertically, the flow control valve should control the oil entering the cylinder. Here again the manifold and cartridge valve system should be considered.

(f) Reservoirs. Hydraulic fluid reservoirs should have a minimum capacity in gallons of about three times the maximum pump capacity in gallons per minute (gpm). There are other factors also that must be considered in sizing of a reservoir. If the reservoir is cross-connected to another system to serve as an emergency backup, then an analysis of the potential "overfill" or "overempty" of the reservoir must be accomplished. This is due to the increase or decrease in the volume of the operating cylinder to which it is cross-connected. Long line runs and thermal expansion of the fluid must also be taken into consideration when sizing the reservoir. In any case, the reservoir should have a capacity to always provide a flooded suction to the pump. The interior of the reservoir should be coated with a good epoxy coating system suited for hydraulic service. The reservoir top, sides, and bottom should be fabricated of heavy steel plate, 1/4 in. to 3/8 in. thick, annealed and pickled. Internal reinforcing should be provided to ensure sturdy mounting for the pump unit, with vertical oil baffles to separate oil return from the pump inlet, and to provide a nonturbulent flow of oil to the pump suction. Consideration should be given to providing vibration isolation between the pump base and the oil reservoir to minimize noise transmission. Reservoir accessories such as suction filter, oil level gage, low level shutoff switch, magnetic particle unit, drain valve, removable clean-out plates (both ends), reservoir heaters (if required), and replaceable filter breather cap should be provided. Where reservoir heaters are used, the watt density should not exceed 10 watts per square inch. When a free-standing reservoir is used with a central system, it should be of such size as to promote cooling and contaminant separation and allow thermal expansion of the fluid and changes of fluid level due to system operation. The design minimum fluid level should be high enough to prevent vortex formation at the pump inlet opening. Adequate pump suction submergence should be available from the pump manufacturer. Many central systems have been built with free-standing tanks of approximately 1,000-gallon (gal) capacity.

(g) Filters. To provide initial cleanup and continuous filtering of the hydraulic oil, a full flow, removable-cartridge-type oil filter should be provided in the return line. Pressure gages should be installed on the filter tank to indicate pressure drop across the filter. Also, a filter cartridge replacement indicator would be beneficial to maintenance personnel. A system should be provided to indicate when oil is bypassing the filter. Filter elements should be capable of removing particulate matter of 10 micrometers, with a filtration ratio (Beta) of $B_{10} = 75$. The Beta (B_n) is the ratio of the number of particles greater than a given size (n) in the influent fluid to the number of particles greater than the same size (n) in the effluent fluid. ANSI B93.30M should be referenced for the B_{10} filtration ratio test procedure. Since proper operation of the control valves, relief valves, and pumps depends on the cleanliness of the oil used, it is a very important consideration in the design of the hydraulic system. Very rigorous specifications should be prepared requiring recirculation of all oil in the system through the system filter before the unit is put into operation. When a separate pilot pressure pumping system is provided, an in-line, system pressure filter with a replaceable cartridge should be furnished in the pump discharge line.

(h) Accumulators. Accumulators should be used in systems with long lines to minimize the effect of system shock pressures.

(i) Piping. Piping for hydraulic systems which are free from appreciable shock, vibration, and external load should be designed for a safety factor of six based on the operating pressure. Where severe shock, mechanical abuse, or vibration are likely to occur, then a safety factor of eight should be used. Where flexible hoses are used they should be designed with a minimum safety factor of eight. Also, exposure to the elements, any abnormal equipment hazard, and chafing are elements to be considered in the design of flexible hoses. Normally, piping should be seamless, black steel pipe, pickled and oiled with forged steel weld fittings. Piping 2 in. and smaller should use socket-weld-type fittings, and over 2-in. piping should use butt-weld type. Where piping crosses under the lock chamber, or other applications subject to very corrosive conditions, stainless steel pipe and fittings should be used. Hydraulic tubing with flare- or swage-type fittings may be used with package-type pump units. Expansion joints are normally not required, or recommended; however, every piping system should be analyzed and adequate provisions made for pipe expansion and movement. Pipe hangers should be of a type that are not rigidly connected, in order to prevent breakage from line shock or pipe movement within the hanger. Some desirable features that should be considered for maintainability of a hydraulic piping system are:

(1) Piping should be pitched a minimum of 1/2 in. per 50 ft in order to provide high and low points.

(2) Air bleed valves should be provided at high points in the system.

(3) Drain valves should be provided at low points in the system.

(4) Periodic shutoff valves should be provided, especially in long runs, to facilitate maintenance without complete system drainage.

(5) Periodic pressure gage ports with gage cocks should be considered for installation of gages for system troubleshooting.

With the central pumping system, supply and return lines at the ends of long runs of piping should have a valved cross-connection to permit start-up, or periodic flushing. Piping for hydraulic systems should be hydrostatically tested at 150 percent of system design pressure.

(j) Fluid velocity and pressure drops. The selection of fluid velocity for the computation of pipe friction is, in general, a compromise between limitations of pressure drop and limitations of line size. The following paragraphs indicate the general range of velocities acceptable.

(k) Pressure supply lines. The velocity in supply lines is generally held between 10 and 15 feet per second (fps), although for very short lines, as used in the package-type unit, velocities up to 20 fps are not considered excessive.

(l) Return lines. Generally the velocity in return lines is kept basically the same or slightly less than the velocity in supply lines.

(m) Pump suction. Velocities in pump suction lines normally are in the range of 2 to 5 fps. Pump suction lines deserve special attention to velocity since the pressure drop in the line together with the pressure drop through a suction filter, if used, can be detrimental to pump performance, especially during cold start-up. Excessive pressure drop in the pump suction line is a frequent cause of pump cavitation.

(n) Drain lines. Although flow in the drain lines from the valves is normally very small, velocity must be kept low to avoid pressure drop which is reflected as back pressure on the drain port of the component being drained. Excessive back pressure in draining can result in malfunctioning of valves and damage to seals. Component manufacturer's limitations on maximum allowable back pressure on drain ports should be followed in all cases. If the component being drained is located below the level of the fluid in the reservoir, the pressure due to static head must be added to the pressure drop to determine the total back pressure. In computing the velocity in drain lines, the fluid flow should be based upon the maximum allowable drain flow at which replacement or overhaul is required, rather than the flow from a new component, and should be based upon the viscosity of the fluid at operating temperature.

(o) Pilot lines. Normally the flow through pilot lines is small enough so that velocities will be low. In any event velocities should not exceed 10 to 15 fps.

(p) Hydraulic fluid. A petroleum oil with a high viscosity index should be selected to minimize the change in pipe friction between winter and summer months. The oil selected must have a viscosity range suitable for the system components and their expected operating temperature range. Generally, the maximum viscosity range is between 4,000 Saybolt Universal seconds (SSU) at start-up and 70 SSU at maximum operating temperature. However, this range will vary between

manufacturers and types of equipment. In the case of a system containing a large quantity of fluid, rust and oxidation inhibitors should be added. An alternate to the above-recommended hydraulic fluid is a relatively new biodegradable and nontoxic fluid. This fluid uses vegetable-based oils and synthetic additives to provide specific properties which are required in hydraulic fluids.

This fluid meets some pump manufacturers' requirements, but it does not meet all manufacturers' requirements, as of this date, so care must be exercised in selecting this fluid. Also, there is only one manufacturer which produces this fluid at present. This fluid, while clear when new, turns amber with age and usage. This may or may not be a problem.

Chapter 2
Miter Gates

2-1. Miter Gates, Horizontally Framed

a. Stress analysis. The primary structural elements of a single gate leaf consist of a series of horizontal girders, connected vertically by a skin plate, two end diaphragms, and a number of intermediate diaphragms. (See Plate B-1.) The horizontal girders are in effect a series of three-hinged arches which transmit the water pressures to the lock walls through the quoin hinges. They are subjected to combined bending and direct stresses. The system of vertical diaphragms forms a series of vertical continuous beams supported by the elastic horizontal girders.

(1) In the following general solution for a three-hinged arch, the vertical stiffness of the gate leaf is neglected. Figure 2-1 shows a horizontal girder (half of a three-hinged arch) acted upon by water pressure due to differential head varying in magnitude with the depth of the girder below the water surface and the panel width which it supports. The following symbols are used throughout to describe reactions in the mitered position.

R = reaction of the girder at the wall quoin and miter blocks

N = component of R perpendicular to work line of leaf

P_1 = component of R parallel to work line of leaf

P_2 = the corresponding water force on the end of each girder, determined from the water pressure on the surface extending from the contact point to the upstream side of the skin plate

W = total corresponding water force on each girder, determined by the pressure and the length of the leaf, adjusted by the effective width of damming surface. (See Figure 2-1 and Plate B-3 for the relation of R, N, P_1, and P_2 to the total force W.)

(2) The three-hinged arch formed by the two leaves is symmetrical about the center line of the lock, and, therefore, the miter end reaction R is perpendicular to this center line. If R is extended to intersect the resultant water load W, and from this point of intersection a line is drawn to the point of contact at the quoin end, this line will give the work line which connects the quoin and the miter contact points. The angle θ is the complement of one-half of the miter angle. Referring to Figure 2-1, the bending moment at x distance from the contact point:

$$M_x = \frac{w}{2} [L(x) - L(a) \cot \theta + (t - a)^2 - a^2 - x^2] \quad (2\text{-}1)$$

Bending moment at center of span x = L/2

$$M_c = \frac{w}{2} [L^2/4 - L(a) \cot \theta + (t - a)^2 - a^2] \quad (2\text{-}1a)$$

Bending stress in upstream extreme girder fiber:

$$f_{b1} = \frac{w(t-a)}{2 I} [L(x) - L(a) \cot \theta + (t - a)^2 - a^2 - x^2] \quad (2\text{-}2)$$

where

I = moment of inertia of the girder

Bending stress in downstream extreme girder fiber:

$$f_{b2} = \frac{w(d-t+a)}{2 I} [L(x) - L(a) \cot \theta + (t - a)^2 - a^2 - x^2] \quad (2\text{-}3)$$

Axial stress in the girder:

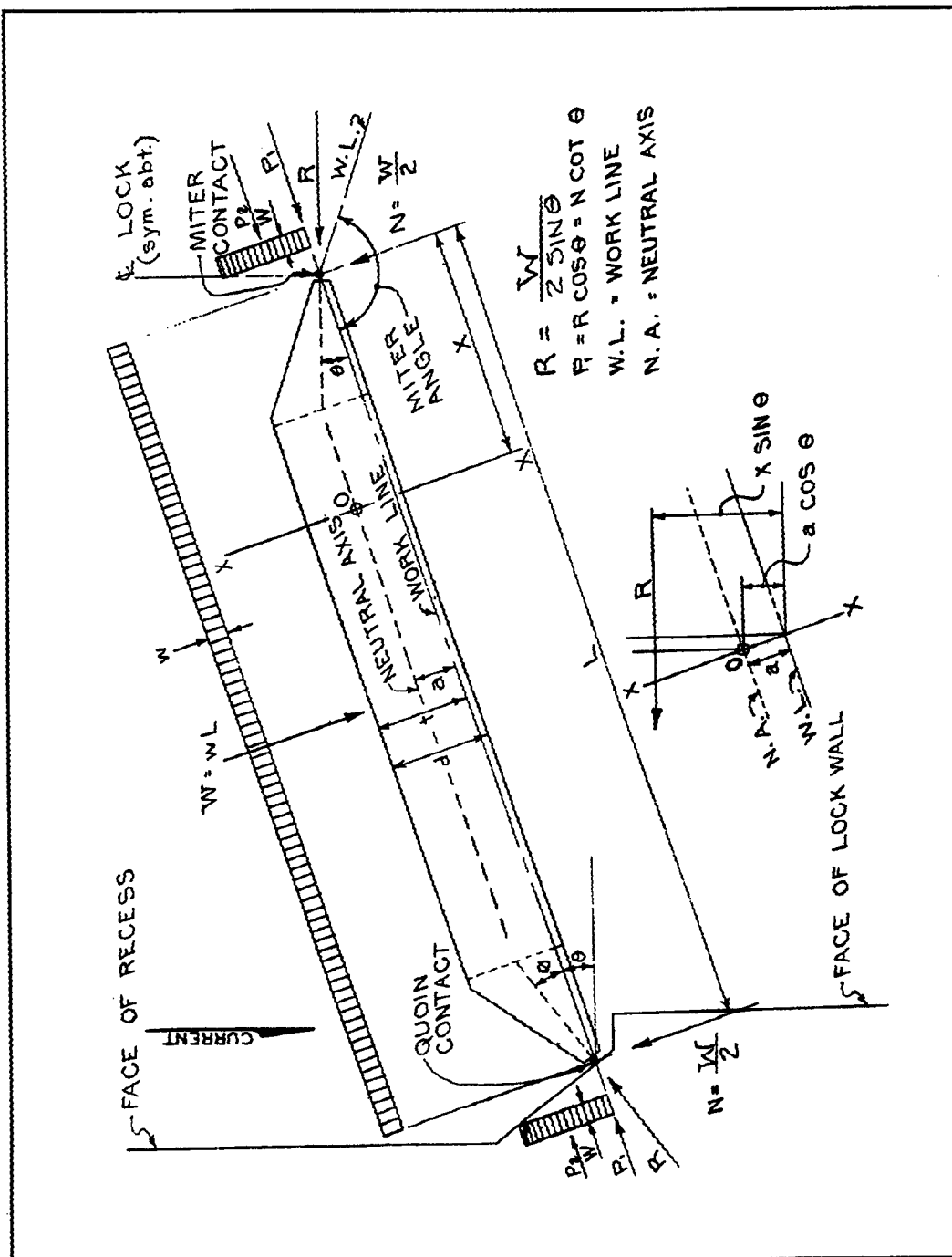$$f_a = \frac{w}{A} [L/2 \cot \theta + t] \quad (2\text{-}4)$$

where

A = cross-sectional area of girder

Combined axial and bending stresses:

Upstream flange:

$$f_{c1} = f_a + f_{b1}$$

or

Figure 2-1. Miter gates, horizontally framed, typical girder data

$$f_{c1} = f_a + \frac{w(t-a)}{2I} [L(x) - L(a) \cot \theta$$
$$+ (t-a)^2 - a^2 - x^2]$$

(2-5)

Downstream flange:

$$f_{c2} = f_a - f_{b2}$$

or

$$f_{c2} = f_a + \frac{w(d-t+a)}{2I} [L(x) - L(a) \cot \theta$$
$$+ (t-a)^2 - a^2 - x^2]$$

(2-6)

(3) For small values of x, the downstream flange will be generally in compression. As x is increased toward the midpoint of the leaf, bending stresses will increase so the downstream flange will be generally in tension. Hence, by moving the work line downstream, a saving in weight may be achieved in the center portions of the leaf where the upstream flange is in compression and the downstream flange is in tension or less compression. Considering the girder as a whole, then, the work line should be as far downstream from the neutral axis as is practicable.

(4) The foregoing analysis of the statically determinate forces and stresses affecting the horizontal girders of a gate will serve to indicate approximate dimensions. Common practice is to design the lower girders of the gate for full hydrostatic loads, and to assign loads greater than the hydrostatic to upper girders. These additional loads give greater vertical stiffness to the leaf and approximate tow impact loads.

(5) Initial approximate dimensions may be taken as follows (see Figures 2-1 and 2-2).

(a) A common value for θ is arc tan 1/3 = 18 deg, 26 min, 6 sec, which gives an exact bevel of 1L on 3T (L = longitudinal, T = transverse).

(b) The length of the leaf then becomes 0.527 times the distance between quoin contact points of the gate.

(c) A first trial value, for gates of moderate height, for the depth d may be taken as 0.07 times the length of the leaf, but a minimum depth of 48 in. Refer to paragraph 2-1d(3) for additional guidance.

(d) The distance from the downstream girder flange face to the work line $(d - t)$ may be set at a practical minimum of 4 in.

b. *Loads and reactions.* The following loading conditions represent various combinations of loads and forces to which the gate structure may be subjected:

(1) Loading condition I. Working stresses specified in paragraph 1-7b will be applied to loads listed below:

(a) Dead load (including ice, mud, etc., on leaf).

(b) Live load (bridgeway and walkway live loads without impact).

(c) Water pressure (hydrostatic load due to pool differential).

(d) Barge impact load (point of load applied above pool at miter point (symmetric impact), and anywhere to within 35 ft, the standard barge width, of either lock wall (unsymmetric)).

Impact, I = 250 kips (symmetric)
I = 400 kips (unsymmetric)

(e) Gate diagonal prestress loads.

(f) Operating strut loads on gudgeon pin assembly, eye bars, and embedded anchorage. Normal submergence and obstruction are assumed with gate leaf in the recessed and mitered positions.

(2) Loading condition II. When the loading includes in addition to condition I loads any of the loads listed below, a 1/3 overstress of working stresses specified in paragraph 1-7b will apply:

(a) Earthquake loads (inertia force of gate mass plus dynamic water load).

(b) Water loads (increased hydrostatic loads due to dewatering for maintenance).

(c) Thermal stresses.

(d) Wave loads, including reverse head due to temporal loads (overfill, overempty, etc.)
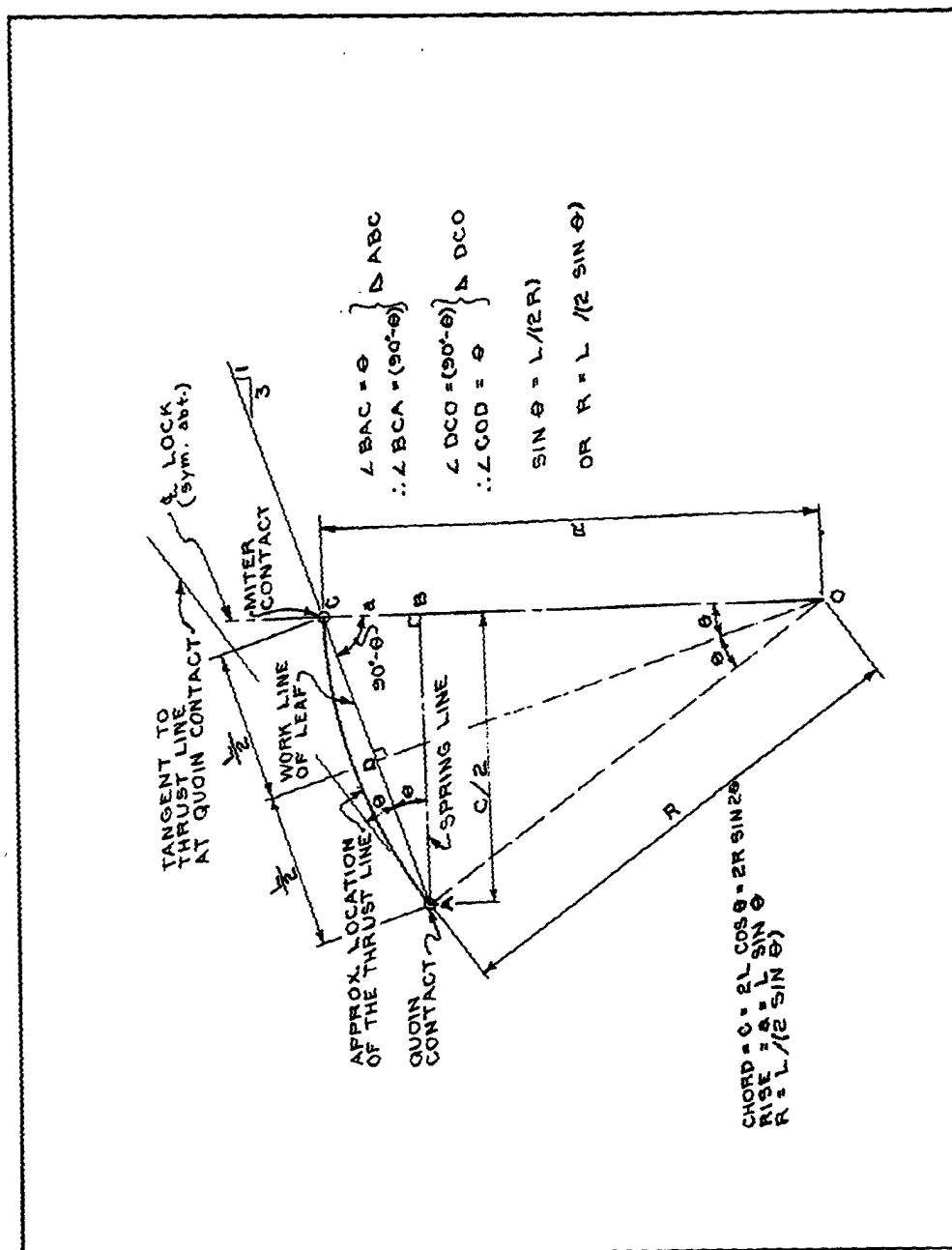
(e) Wind loads.

Figure 2-2. Miter gates, horizontally framed, gate geometry

(3) The loads causing gate leaf deflection and torsion during operation of the miter gate are determined as follows: The bottom edge of the leaf is assumed to be held (zero deflection) by water and/or submerged obstruction, the vertical quoin edge is supported by the gudgeon pin and the pintle assembly. Maximum machinery load is applied to the top of the leaf under the above-described edge support conditions. This machinery load deflects the leaf causing an increase or decrease in tension in the prestressed diagonals and torsional stresses in the horizontal girders.

(4) Gate reactions are basically divided into two categories: one, with the gate in the open or intermediate position with no water load; or two, with the leaves mitered and supporting the full hydrostatic load. With the gate in the unmitered (intermediate or open) position, the leaf reactions are couple-forces, applied at the gudgeon pin at the top and the pintle at the bottom. The top couple-force is made up of the gudgeon pin reaction force combined with the operating strut force, while the bottom or pintle force results from the leaf reaction on the pintle. Leaf reaction and strut forces due to all loading conditions defined above will be considered in determining the governing force combinations for design of the gudgeon pin and pintle assemblies. (See Plate B-8.) With the gate adhering and the full hydrostatic load applied, each horizontal girder carries a portion of the water force to the wall monoliths.

   c. *Skin plate, intercostals, and diaphragms.*

(1) Skin plate. The skin plate is located on the upstream face of the girders and is designed for the water load, with the edges of panels assumed fixed at the center line of intercostals and the edge of girder flanges, except that where the flanges are greater than 12 in. wide the skin plate is assumed fixed at a point 6 in. from the center line of the web. The skin plate is also considered an effective part of the upstream girder flange. When a section has a skin plate of a higher yield than the rest of the girder, the effective width of skin plate shall be determined by the higher yield point. Due to the combined loading the skin plate shall be checked for biaxial stress, composed of skin plate action and beam action. The Huber-Mises formula is convenient for checking biaxial stresses.

$$S^2 = S_x^2 - S_x S_y + S_y^2 \qquad (2\text{-}6)$$

where

S = combined stress $\leq 0.75\ F_y$

S_x = normal stress in x direction

S_y = normal stress in y direction

F_y = minimum yield stress of steel being used

The most effective panel shape for a skin plate is a square, but due to maintaining a uniform intercostal spacing from top to bottom of the leaf, and the variable girder spacing, the panels are usually rectangles, with a ratio of the short side to the long side of the panel, varying from about $\pm$ 0.45 at the upper panels to approximately 1.0 on the more critical lower panels. Assuming a rectangular panel with all edges fixed, the following symbols and formulas are used to determine stress in the skin plate from water force only. (See Roark and Young 1975.)

w = unit load at the center line of the panel (average head)

a = greater dimension of the panel

b = smaller dimension of the panel

q = ratio of b to a

t = thickness of plate

Stress at the center line of the long edge =

$$\frac{0.5wb^2}{t^2(1 + 0.623q^6)}$$

Stress at the center line of the short edge =

$$\frac{0.25wb^2}{t^2}$$

(2) Intercostals. Intercostals are designed as vertical fixed end beams supported at the center line of girder webs.

(a) An effective section of skin plate is assumed as acting with the intercostal, the effective width determined in accordance with the AISC Specifications. (Unstiffened elements under compression.)

(b) An average water pressure (head at the center of the panel supported by the intercostal) is used for design of the intercostal, with the loading extending from edge to edge of flanges (maximum of 6 in. from center line of girder web).

(c) When the skin plate is of low-alloy steel and the intercostal is of structural grade steel, the acting composite section of skin plate and intercostal shall be governed by the allowable stress for the lower strength material. (See Figure 2-3 for additional information on intercostals.)

(3) Diaphragms. The end diaphragms are designed as panels acting as skin plate, with the effective panel being between the stiffener angle and the next lower girder. The stiffener is located at midpoint between girders. The head at the center of the effective panel is used as the design pressure. Intermediate diaphragms should be spaced and sized as follows:

(a) To provide adequate supports for horizontal girders (weight and lateral buckling).

(b) For shear forces resulting from the diaphragms tending to equalize differential deflections between adjacent horizontal girders due to variation of hydrostatic and impact loads.

(c) For operating machinery, jacking support, and diagonal tension-related loads.

The critical buckling stress should be kept below 70 percent of the yield stress of the diaphragm material. On smaller gates the intermediate diaphragms are made a minimum of 3/8 in., while the minimum for larger gates is 1/2 in. Generally the end diaphragms are made a minimum of 1/2 in. for all sizes of gates. Diaphragms are made as deep as the girder webs, and stiffeners the same size as the longitudinal web stiffeners are used as vertical stiffeners on the intermediate diaphragms. For determining critical buckling stresses in flat plates in edge compression and shear and establishing allowable diaphragm panel sizes refer to Timoshenko (1936), Bleich (1952), and Priest (1954).

d. Horizontal girders. Horizontal girders lie along a chord of the thrust line curve, with the resulting eccentricity of thrust producing bending stress in addition to the axial stress.

(1) The girders are so spaced that variation in the girder flange sizes and skin plate thicknesses are held to a minimum. The spacing usually varies from a maximum of 6 ft at the top to a minimum of 4 ft at the bottom of the leaf. Each girder should be equal to or smaller than the one immediately below, with the exception of the top girder. Girder spacing also influences the size of intercostals.

(2) The loads on each girder are determined by taking the average water load per linear foot of girder. While this gives slight variation from the exact loading for some girders, (generally two girders per leaf) the average is considered to be more than accurate enough for the usual gate loading. Consideration should be given to any special loading condition to determine if the actual loading should be used instead of the average described above. The boat impact loads are usually governing for the uniformly spaced upper girders.

(3) The ratio of the depth of girder web to the length of leaf varies from 1/8 to 1/15 for most gates, the greater value occurring on gates having the higher heads. Deeper girders make the leaf torsionally stiffer but may require web stiffeners. The appropriate sections of the AISC specifications shall be used to check for web buckling and web crippling. Horizontal girder webs should be stiffened with horizontal stiffeners to meet the criteria for web buckling for axial loaded columns using the diaphragm spacing as the effective column length. Minimum horizontal stiffeners are generally used on girder webs even though not required by web buckling. The minimum width of stiffeners shall be 3-7/8 in., used where the minimum flange width of 8 in. is used.

(4) Minimum thickness of material shall be 3/8 in. for webs and stiffeners and 1/2 in. for flanges. The minimum width of flange plates shall be 8 in. for the upstream flange and 12 in. for the downstream flange, with the exception of the bottom girder. The downstream flange of the bottom girder can be a minimum of 9 in. wide, with 3 in. below the center line of the web to provide additional clearance between bottom girder and sill. For the end sections of the bottom girder, where the downstream flange is heavier, the upper portion of the flange can be made a maximum width of 15t above the center line of the web, maintaining the 3 in. below the web center line and limiting the overall width of the flange to 1 ft 3 in. For all other flanges the maximum overall width should be limited to 24t, thereby reducing the possibility of flanges being undesirably wide and thin. The use of cover plates is not recommended for the usual gate design. (See Plates B-3 and B-5.)

TRIANGULAR LOADING

$$FEM = -\frac{g_x S}{2} \times G \left(\frac{3-2\gamma^2}{24}\right) = \frac{g SG(3-2\gamma^2)}{48}$$

$$SBM_{\mathbb{C}} = \frac{g S^2}{12} + \frac{g SF}{8}$$

NOTE:
IF $F \geq 12"$ — $S = G-F$
IF $F > 12"$ — $S = G-12"$
$F = $ FLANGE WIDTH; $\gamma = S/2G$

TRAPEZOIDAL LOADING

$P = hw$ $G 2.5 h$ $m = \frac{1}{8}(3F+4a)n = \frac{1}{6}(6b+8a+3F);$

$l_P = \beta$; $\alpha = a/s$; $\mu = m/G ; \nu = \frac{a}{3G} ; \delta = \frac{a}{3G} ; K = \frac{F+2a}{2G}$

$$FEM = -\frac{g G^2}{12}[1-6K^2\gamma+4K^3] - \frac{g \pi a}{2}[\mu \nu - \frac{5(3\nu-1)+2 g S^2}{10 \nu}]$$

$$SBM_{\mathbb{C}} = \frac{g S^2}{24}(3-4\alpha^2) + \frac{1}{4} g F(\alpha+b)$$
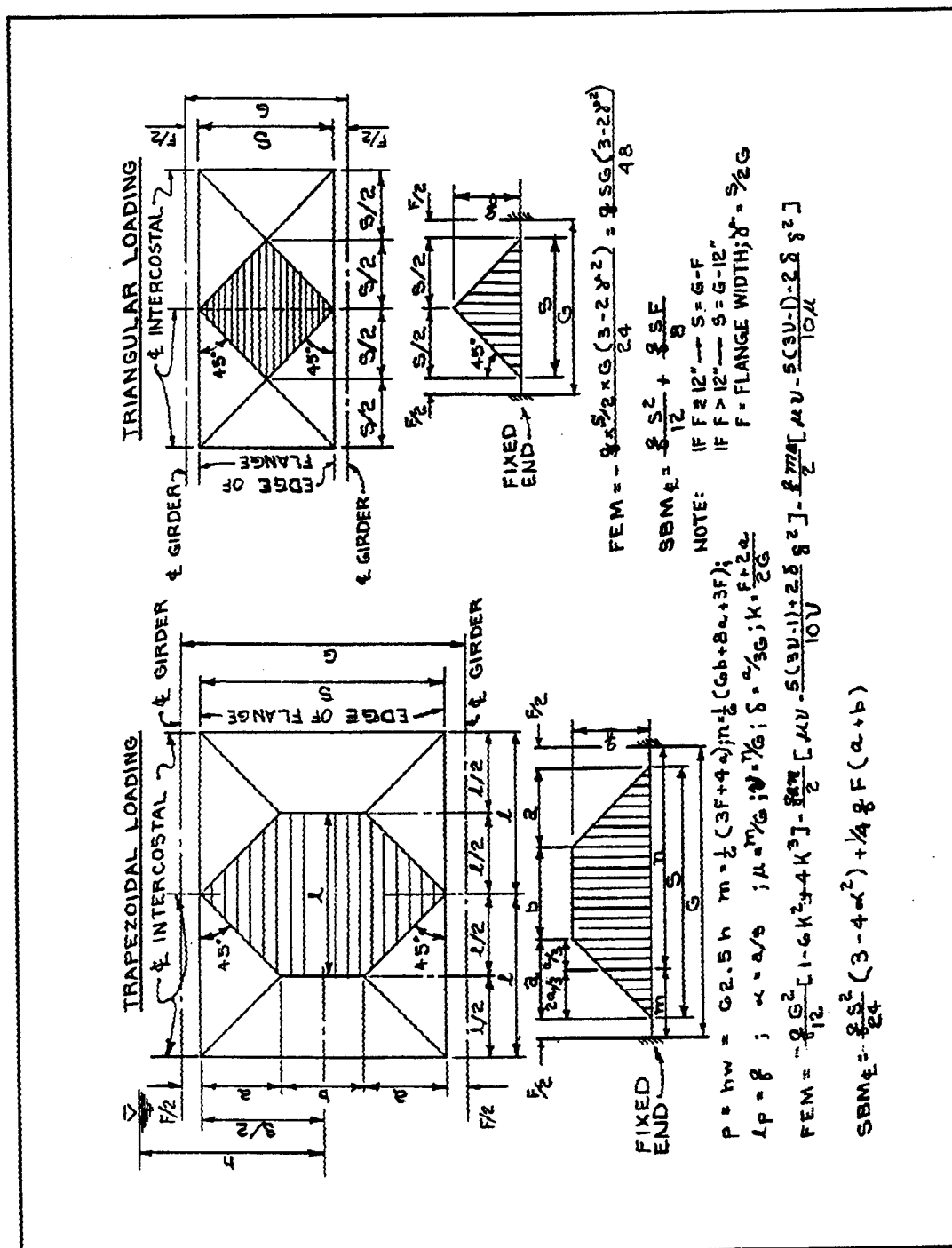
Figure 2-3. Miter gates, horizontally framed, intercostal loadings

(5) The maximum extension of skin plate above the center line of the top girder is 8 in., to prevent interference with the operating strut. The maximum extension of skin plate above the top flange should not be over 1/2 in., limiting the maximum width of the upstream flange for the top girder to 1 ft 3 in.

(6) Buckling of the girder about the major axis is not a concern since the skin plate provides lateral support to each girder. However, lateral stability of the downstream flange should be checked where that flange is in compression near the end diaphragms.

(7) The girder should be checked for buckling about the minor axis. The length shall be taken as the distance between quoin and miter bearings, with $K = 1$. The radius of gyration to be used may be calculated for the center part of the girder. However, this may be slightly overconservative. If this calculation shows that buckling strength is a controlling condition, use the following more realistic value for the radius of gyration.
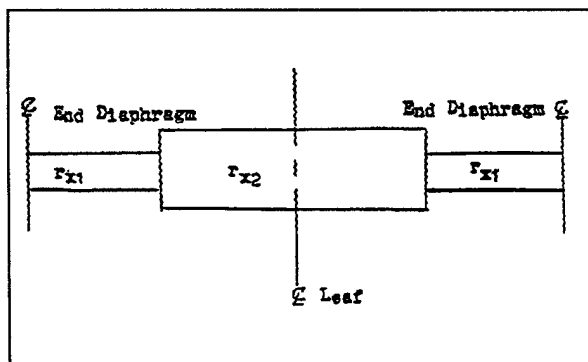
$$r_x = (L_1 \times r_{x2}) + \frac{2(L_2 \times r_{x1})}{L_1 + 2(L_2)} \qquad (2\text{-}7)$$

where

r_{x1} and r_{x2} = major axis radius of gyration of respective sections

L_1 and L_2 = lengths of respective sections

For additional information, see USAEWES (1987).

(8) The web depth-to-thickness ratio should be such that no reduction in flange stress is necessary. See the AISC specifications for the maximum ratio.

(9) Transition of flange widths at butt joints shall be governed by the applicable provisions of Structural Welding Code, AWSD1.1. The maximum change in flange width, on the same edge of a girder web, shall be 6 in., with a 3-in. differential on each edge of the flange, with the exception of the downstream flange of the bottom girder, where the total 6-in. differential may be on the upper edge of the flange. This applies between the section at the center line of a girder, where the upstream flange is a maximum width and the downstream flange is a minimum width, and a section at the end of a girder where the upstream flange is a minimum width and the downstream flange is a maximum width. A tapered flange transition is also preferred where all horizontal and vertical flanges connect to gusset plates with the maximum change being as previously described.

(10) The flanges of the bottom girder are offset from the center line of the girder web as indicated by the preceding paragraphs. The downstream flange should extend 3 in. below the center line of the girder web, from end to end of girder, to allow for clearance between the flange and the sill. The upstream flange should extend 6 in. below the center line of the girder web, from end to end of girder, with the skin plate 1/2 in. above the lower edge of the flange. A minimum of 4 in. should be used above the center line of the web, thereby making a minimum width of 10 in. for the upstream flange of the lower girder. (See Plate B-5.)

(11) The load in the diagonal is resisted by members connected to the gusset plate. The horizontal component of this load is distributed among several girders. The design of all girders attached to the gusset plate shall include provisions for this additional eccentric axial load. A discussion of the distribution of this load among the girders may be found in Technical Report ITL-87-4, Report 7 (USAEWES 1987).

(12) Drain holes shall be provided in all girder webs except the top girder where the drain holes shall be placed in the upstream flange, since the web of the top girder forms part of the damming surface during high water.

(13) The critical point for the tapered end sections occurs at a distance Z' from the center line of bearing.
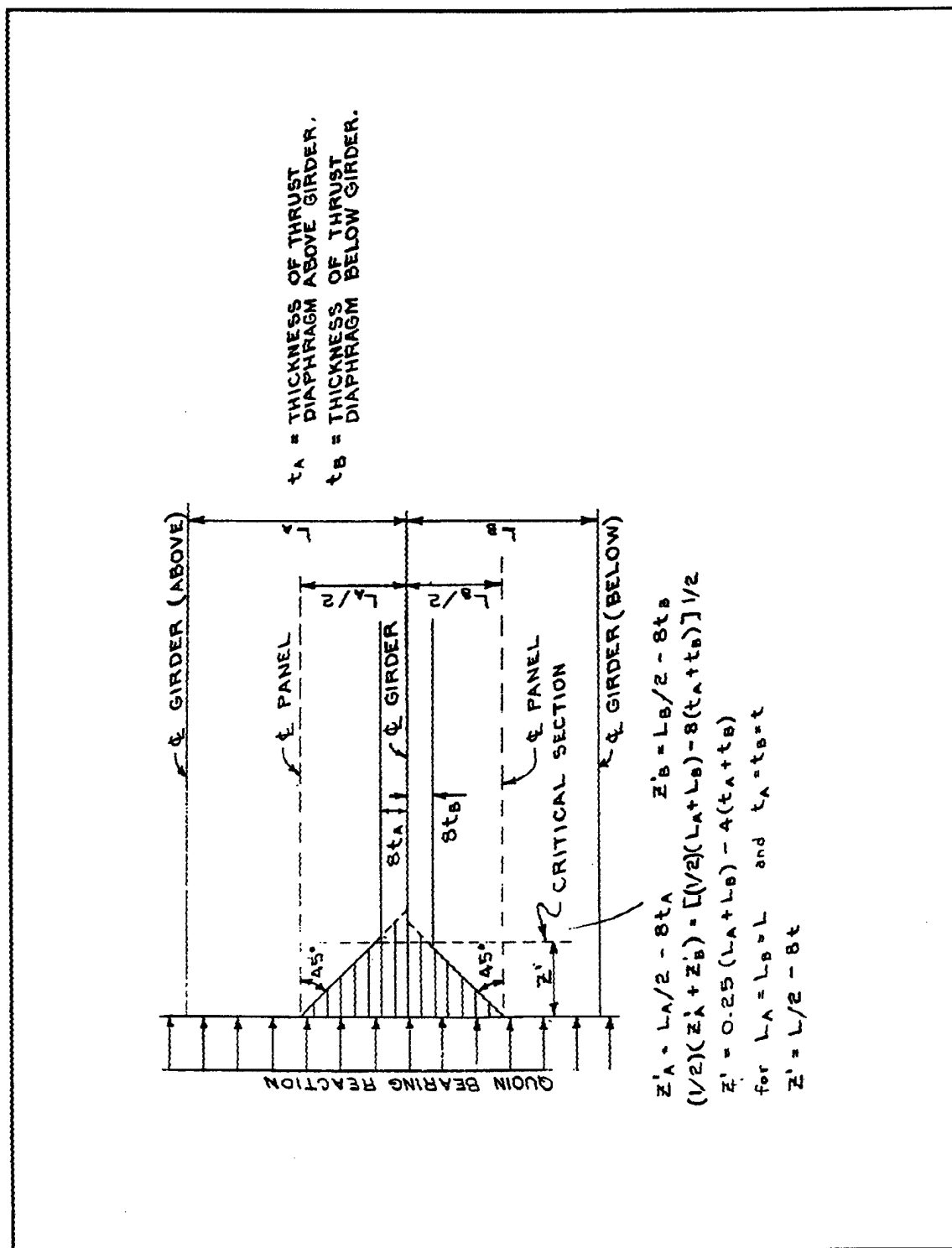
$$Z' = \frac{\text{span} - 16t}{2}$$

Figure 2-4. Miter gates, horizontally framed, load distribution, tapered end

where the span is the smaller span adjacent to the web under consideration and t is the thickness of the thrust diaphragm. (See Figure 2-4.) Due to the short lengths involved, F_a and F_b are equal to the basic stress of 0.50 F_y.

(14) The moment is determined by assuming a cantilever section equal in length to Z' with a water load equal to w, plus the moment created by R being eccentric from the centroid of the section. See paragraph 2-1e on the thrust diaphragm for more information relating to the distribution of stress from the end plates to the webs.

(15) The web thickness of the tapered section is increased to keep the stress within the allowable limits. If a thicker tapered end web is required, this thickness is carried 12 in. past the end diaphragm. This may vary on the bottom girder where the stiffeners for the jacking support may interfere. A check should be made for concentrated stresses in the web just inside the end diaphragm. This stress is caused by the thrust diaphragm ending, transferring its load into the web. It is recommended that 20 percent of the thrust diaphragm load and an area of 40 percent of the web depth and corresponding thickness, including any stiffeners in the area, be considered for the check. The bottom girder web thickness over the pintle is 3/4 in. minimum and machined to a 250 finish or match the machine finish to the top of the pintle socket casting. (See Figure 2-5.) The top and bottom webs are wider at the quoin end to accommodate the gudgeon pin and pintle. (See Plates B-3, B-4, and B-5 for additional information on girders.)

e. Thrust diaphragms. The thrust diaphragm is tangent to the thrust curve at the contact point and is approximately in line with the thrust curve between the contact point and the end diaphragm, which is the limit of the thrust diaphragm. The thrust diaphragm serves to distribute the reaction of the girders from the quoin block into the girder webs. It also acts as the damming surface between the end plate and the end diaphragm. Part of the thrust diaphragm is also considered effective in the quoin post, making it subject to bearing, skin plate, and column action stresses. Shear between the web and thrust diaphragm is to be checked also, but is not combined with the above-listed forces. The allowable stress for the combined bearing and skin plate action, occurring adjacent to the end plate, is limited by the elastic limit or 0.70 F_y, whichever is the lesser value. The stress in the thrust diaphragm is assumed to follow a 45-deg angle from a point midway between girders, up to the effective

web section. The effective section consists of the web, flanges, and a portion of the thrust diaphragm. See Figure 2-4 for the layout of this stress pattern for the tapered end section. The elastic limit may be determined by assuming the panel under consideration to be clamped on all edges and equal uniform compression on two opposite edges, with the critical stress equal to $K[E/(1 - v^2)](t/b)^2$

where

    a = longer dimension of panel

    b = shorter dimension of panel

    v = Poisson's ratio

    t = thickness

    K = 7.7 for a ratio of a/b = 1.0

    K = 6.7 for a ratio of a/b = 2.0

    K = 6.4 for a ratio of a/b = 3.0

See Roark and Young (1975) for additional information on elastic stability.

f. Quoin post. A section of the thrust diaphragms, vertically from top to bottom girders, forms a column to support the dead weight of the leaf. The end plate and two vertical stiffeners form one flange of the column; a plate perpendicular to the thrust diaphragm, with vertical stiffeners on the outside edges, form the other flange. See Plate B-5 for a typical layout of the quoin post. The axial load on the quoin post consists of the dead weight of the leaf plus ice and mud load. Due to the eccentricity of the pintle and gudgeon pin with respect to the centroid of the quoin post, the quoin post is subjected to an axial stress and bending stresses, plus the skin plate action of the thrust plate.

$$\text{Stress} = \frac{P}{I} + \frac{Pec}{I_x} + \frac{Pec}{I_y} + \text{skin plate stress} \qquad (2\text{-}8)$$

The maximum combined stress may occur at the center of the lower edge of the thrust diaphragm panel, shown as point C or at any of the extreme corners of the quoin post cross section shown as points A, B, E, and F in Plate B-5. The allowable stress for the combined loading is limited to the basic stress of 0.50 F_y.
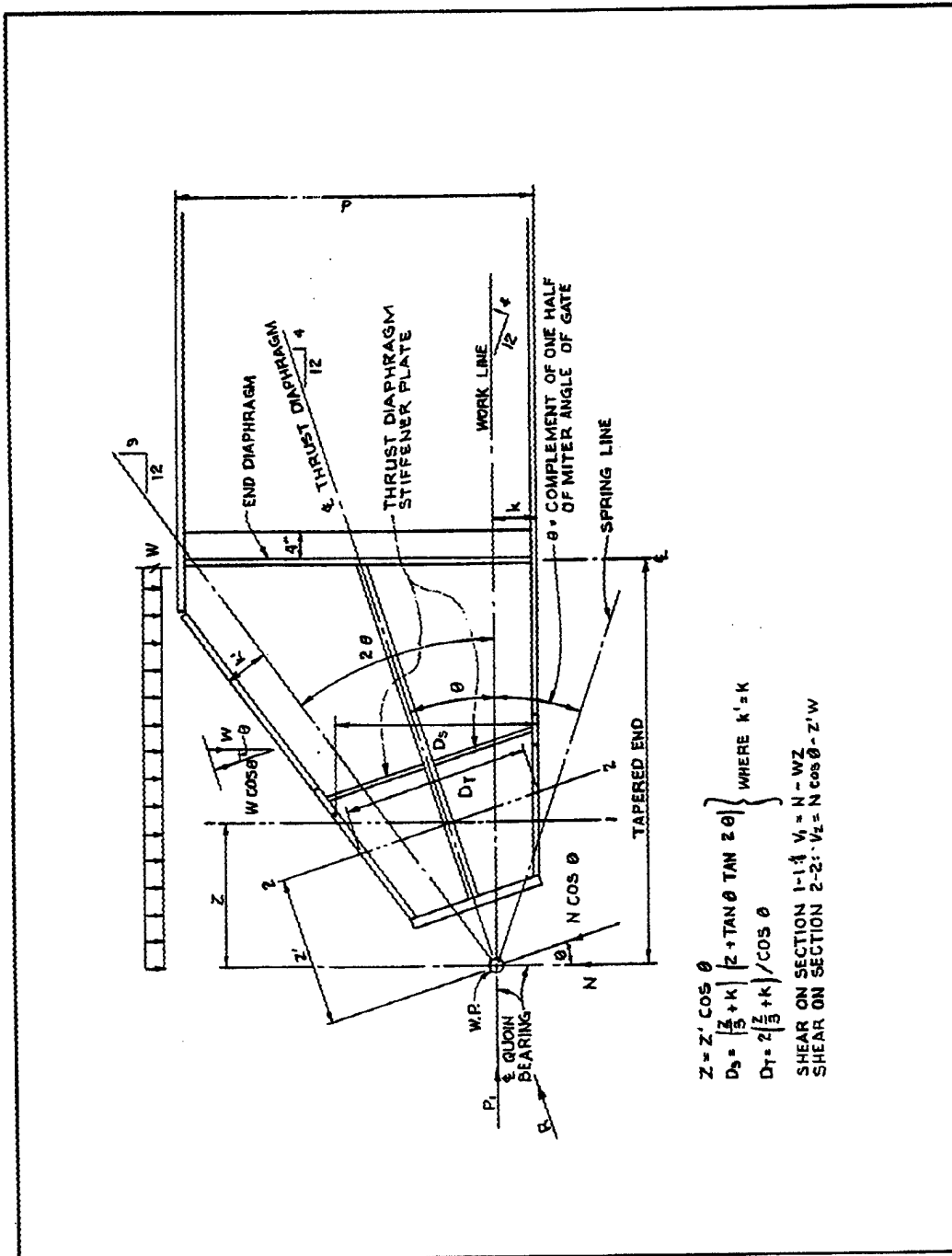
Figure 2-5. Miter gates, horizontally framed, typical end shear, tapered end

g. Gudgeon pin hood and anchorage.

(1) Gudgeon pin and hood. The gudgeon pin hood is an arrangement of plates forming the hinge connection at the top of the miter gate leaf. (See Plate B-6.) The commended distance between the center line of the top web and the center line of the top pin plate is 1 ft 6-3/4 in. This is with a 1-in. top pin plate and 1-1/4 in. pin plate welded to the top girder web. The top pin plate has sections of it sloping from the 1 ft 6-3/4 in. height down to the girder web. The downstream edge of the top pin plate is attached to the 1/2-in. section of the bulkhead plate with a weld. The upstream part of the hood is formed by a vertical plate, normally 3/4-in. minimum thickness, that overlaps the upstream girder flange, with the edge of the vertical hood plate being welded on the center line of the horizontal girder web.

(a) The top pin plate should be designed as a curved beam with a uniform load rather than assume the plate to be an eye bar. Formulas from Seely and Smith (1952), are shown in Plate B-7. The basic stress of 0.50 F_y should control.

(b) The pin is generally made a minimum of 12 in. in diameter, to give an additional factor of safety and to standardize the barrel and hood arrangement.

(c) The pin is usually made of forged alloy steel, ASTM A668, normalized and tempered, with the allowable stresses as referenced in paragraph 1-7*b*.

(d) The bushing is normally of bronze with the bearing pressure kept below 1,500 psi.

(e) Rings of ASTM A36 steel varying in thickness from 1/16 in. to 1/4 in. are used to adjust the vertical clearance between the gudgeon pin barrel and the pin hood.

(2) Anchorage. The anchorage system supporting the miter gate leaves is divided into four basic categories: (a) gudgeon pin barrel, (b) anchorage links, (c) embedded anchorage, (d) pintle and pintle base. While these components act together as a unit, each is designed as an individual unit. The force applied to each of these units is the resultant force of the combined strut force and the dead weight of the leaf, increased 10 percent for impact. The governing loads usually occur at the recessed (open) or mitered (closed) positions of the gate leaf. In order to develop maximum operating strut forces the leaf is assumed obstructed near its miter end. The anchorage system is also checked for temporal loads.

(See Plates B-11 and B-15 for the layout of typical anchorage systems.)

(a) Gudgeon pin barrel. The gudgeon pin barrel, of welded carbon steel plates or forged alloy steel plates, is designed as a continuous beam supported by vertical stiffeners, and at the same time as a curved beam, made up of a horizontal plate and an effective section of the plate cylinder which forms the pin barrel. The minimum thickness of the barrel or horizontal plate should not be less than 1-1/2 in. See Plate B-9 for a typical barrel arrangement and formulas. The alternate method of analysis shown in Plate B-10 may be used in lieu of the more precise method beginning in Plate B-9. While the alternate method stresses vary from the more accurate method, the variations are on the conservative side. Due to the barrel being a critical item the design stresses should be kept low, in the range of approximately 0.33 F_y, using the yield point of the lowest grade steel used in the composite barrel unit. This stress should be the combined stress due to bending and direct stress.

(b) Anchorage links. The links are made up of pinned ends connecting to the embedded anchorage with a threaded section between the embedded anchorage and the gudgeon pin. Each link is designed as a tension or compression member individually, and the two links are checked as a unit, as shown in Plate B-11. An alternate top anchorage is shown in Plate B-15. This assembly is made up of two anchor arms and two gudgeon links. The links are welded to the arm which is normal to the face of the lock wall. Adjustment of this anchorage assembly is accomplished by means of wedges. The design procedure is as described above. The design tension force is the tension load plus 10 percent impact, and the design compression force is the compression load plus 10 percent impact. The links acting as a unit are assumed to have a maximum misalignment of 2-1/2 in. at point B, shown in Plate B-11. This introduces a bending stress in conjunction with the axial load. Allowable tension and compression stresses should be determined in accordance with fatigue criteria of ASSHTO Standard Specifications for Highway Bridges or in accordance with paragraph 1-7*b* of this manual, whichever governs. The threaded section of each link, made up of a forged steel section a minimum of 6 in. in diameter, and a hexagonal sleeve nut are used for adjustment of the gate leaf. Right- and left-hand threads, giving a turnbuckle effect, are recommended, with 1/2-in. square threads being used for the sleeve nuts. After all adjustments to the gate leaf have been made, a channel may be welded between the sleeve nuts to lock them in place. The outside diameter of the section threaded for the sleeve nut

should be the same as the largest dimension of the rectangular section. The rectangular section of the link, a minimum of 6 in. by 4 in., is also made of forged steel. The pin-connected ends of the rectangular sections are designed as eye bars, with the allowable stresses being 83 percent of those shown in AISC. Pins should be designed for both bending and bearing, with the allowable stresses determined as indicated in paragraph 1-7b. The dimensions and sizes shown in Plate B-11 are recommended as a minimum unless special conditions or loadings warrant a variation in some dimensions.

(c) Embedded anchorage. In order to distribute the top reaction of the leaf into a larger segment of concrete, the embedded anchorage is designed as a triangular unit, composed of a heavy member for the hypotenuse and vertical side and a secondary member for the horizontal side. The vertical and horizontal sides of the triangle are normally 9 ft with the hypotenuse forming a 45-deg triangle. The hypotenuse and vertical member are designed as a column or tension member, depending on the direction of the gate reaction. The horizontal or secondary member is for fabrication and construction and is assumed to carry no design load. The reactions of the triangular unit are applied to the concrete through plates or pads on the lower points of the triangle. Bolts are used in conjunction with the bearing plates, with the bolts prestressed so that bearing on the concrete will never be completely relieved by the loads from the gate leaf. See Plates B-12 and B-15 for typical layout of embedded anchorage. The prestressed bolts should have an anchor at the ends to carry the full load, assuming no load transfer through bond and using mastic to prevent bond on the bolts. Bolts should be sized according to load, and the length should be sufficient to extend into at least two lifts of concrete. The use of strain gages or an ultrasonic bolt stress monitor is recommended for determining the desirable loads in the prestressed bolts, as the nuts sometimes bind on one edge and thereby distort torque readings and make the turn of the nut method difficult.

h. Pintle assembly. The pintle and related components support the dead weight of each leaf of the miter gate. The unit is made up of four major components: (1) pintle socket, (2) pintle, (3) pintle shoe, and (4) pintle base. (See Plates B-13 and B-14.)

(1) The pintle socket is made of cast steel and is connected to the bottom of the lower girder web with turned monel or stainless steel bolts. The bolts are sized to carry the gate leaf reaction in shear, but, as an added safety factor, a thrust plate should be welded to the underside of the bottom girder web, with a milled contact surface between the plate and pintle socket. The minimum plate size should be 1-1/4 in. in thickness and 12 in. wide, with a length as required by the girder web. The socket encloses the bronze bushing which fits over the pintle ball. An allowable bearing stress of 1,500 psi is desirable but may not always be practical. The automatic greasing system allows a higher bearing stress but should not exceed 2,500 psi. See Plate B-13 for additional information.

(2) The pintle, generally made of cast alloy steel with a nickel content of 3 to 5 percent, is usually 10 in. to 20 in. in diameter, with the top bearing surface in the shape of a half sphere and a cylindrical shaped bottom shaft. For salt or brackish water locations, pintles should be of forged alloy steel with bearing surfaces of corrosion-resisting steel deposited in weld passes to a thickness of not less than 1/8 in. and machined to the required shape. The pintle ball and bushing are finished to a 16-microinch finish where the two come in contact.

(3) Pintle assemblies used for horizontally framed miter gates are generally two types: fixed and floating.

(a) Fixed pintle. This type of pintle is recommended for new construction and major gate rehabilitation. The pintle fits into the pintle shoe, which is bolted to the embedded pintle base. The degree of fixity of the pintle depends on the shear capacity of the pintle shoe bolts. The pintle should be designed so that after relieving the load on the pintle by jacking, the pintle assembly is easily removable. See Plate B-16 for typical fixed pintle. The pintle base, made of cast steel, is embedded in concrete, with the shoe fitting into a curved section of the upper segment of the base. The curved section, of the same radius as the pintle shoe, is formed so that under normal operation the reaction between the shoe and base is always perpendicular to a line tangent to the curve of both shoe and base at the point of reaction.

(b) Floating pintle. This type of pintle is not recommended for new construction. The pintle is fitted into a cast steel shoe, with a shear key provided to prevent the pintle from turning in the shoe. The shoe is not fastened to the base, thereby allowing the gate leaf to move outward in case of debris between the quoin and wall quoin preventing the leaf from seating properly. See Plate B-13 for typical floating pintle. Damage to the pintle bearing has occurred frequently with this type of pintle due to the relative movement between the pintle shoe and base. The movement can consist of the shoe sliding on the base during leaf operation from either the

mitered or recessed position, until the leaf reaches approximately the midposition, at which time the shoe slides back against the flange on the base. This type of movement is generally visually detectable and causes serious wear. However, an alternative to the floating circular shoe is to make the shoe three sided with one corner having the same radius as the circular shoe, and attach a steel keeper bar to the embedded base in front of the shoe. This would prevent the shoe from rotating on the embedded base and prevent the pintle from moving out of pocket. Again, the degree of fixity would depend on the shear capacity of the bolts in the keeper bar. This alternative will meet the requirements of the fixed pintle as well as the capacity to minimize damage in case of emergency.

(4) The pintle base is designed so that there will be a compressive force under all parts of the base. The value of the compressive force on the concrete will vary from a maximum on one edge to a minimum on the opposite edge. Computations are based on that portion of the pintle above the point under consideration acting as a composite unit. The overturning moment can be found from the horizontal force on the pintle and will be resisted by the reaction on the section being investigated. The eccentricity of the vertical force can be determined by the angle the resultant makes with the horizontal and the distance between the horizontal force on the pintle and reaction on the pintle base.

(5) The center line of the pintle (vertical axis of rotation) is located eccentric (upstream) relative to the center of curvature of the bearing face of the quoin contact block. This center of curvature is on the thrust line. The center line of pintle should be located on the point of intersection of the bisector of the angle formed by the mitered and recessed gate leaf work lines and the perpendicular line from the bisector to the quoin contact point resulting in an offset of approximately 7 in. as in the details shown in Plate B-4. Studies and experience show that eccentricities arrived at by the above-described method will reduce the contact time between the fixed wall quoin and the contact block of the moving gate leaf sufficiently to minimize interference and binding between the bearing blocks. The 7-in. offset will be exact and constant for all gates with the same miter angle and distance from the face of lock chamber to the recessed work line (1 ft 2-1/2 in.) as shown in Plate B-4 and in the example in Appendix C.

i. Operating strut connection. The operating strut connection for horizontally framed gates is generally one of three types, the basic types being the hood, vertical

shaft, and direct acting cylinder. Each type has its advantages and disadvantages, and the selection of which o use can only be made after considering all pertinent factors. The different types are described below with some of the main characteristics given for each one.

(1) Hood-type connection. This connection, commonly used with the Panama, Modified Ohio, or the Ohio type machine is attached to the top girder on a line through the center of the pintle and parallel to the work line of the leaf. Three vertical diaphragms, usually one of the regular intermediate diaphragms and two additional diaphragms, spanning between girders one and two, support the connection in the vertical direction. The hood is designed for both moment and shear with a standard rolled tee, under the center of the pin, and spanning between the vertical diaphragms. The stem of the tee is welded to the underside of the top girder web and the ends of the tee are welded to the three vertical diaphragms. The strut is connected to the hood by two pins, one larger vertical pin and a smaller horizontal pin through the vertical pin, forming a universal joint to minimize moment in the strut. The vertical pin is designed for both moment and shear, with the pin supported by bearing collars and bushings at the upper and lower ends. The bearing collars are attached to the supporting horizontal plates by turned bolts, which are sized for shear. Shear normally will determine the size of the horizontal pin. Plate B-33 shows typical details for the hood-type connection.

(2) Vertical-shaft-type connection. This connection consists of a vertical cylindrical shaft extending through the web of the top girder down to the web of the second girder. It has generally been used with a cylindrical or tubular strut utilizing ring springs. As the shaft is free to rotate in its supporting bearings it is designed for simple moment and shear, with the restraining forces supplied to the shaft by the webs of the first and second girder webs. This arrangement is similar to the vertical pin in the hood type with the exception that the shaft is tapered between the first and second girders. The pin is designed as a cantilever above the top girder. The vertical-shaft-type connection is similar to the vertical pin of the hood-type connection; therefore the details of the vertical shaft connection are not shown in the plates in Appendix B.

(3) Direct-acting-type connection. This connection, while not restricted to them, has normally been used only for direct-acting-cylinder machines. It is bolted directly to a section of the upstream flange of the top girder which is increased in width and thickness and supported by transverse stiffeners on each side of the girder web.

The flange section is designed as a simple beam supported by the stiffeners. The length of the increased section is determined by fabrication requirements and shear between the section and the web. The operating strut, connected by the same universal-type joint as the hood type, consisting of vertical and horizontal pins, applies no moment about the weak axis of the pin plates and eliminates any force except direct forces being applied to the girder flange. See Plate B-33 for typical arrangement of this type of connection.

(4) Comparison of types. The hood-type connection, located on a line through the center of the pintle, avoids increased anchorage forces created by a moment arm from the upstream flange to the center of the pintle. This keeps R_b, as shown in Plate B-8, to a minimum force. The fabrication cost for the hood type will generally be higher than for the other types of connections.

(a) The vertical shaft system is a simpler type of connection than the hood type, and it is also located on a line through the center of the pintle, thereby keeping force R_b to a minimum. The cantilevered length of the shaft above the top girder may be prohibitive for the helical coil spring and wide-flange-type strut.

(b) The direct-acting-type connection is the simplest of the three connections, but as the pin plate assembly is bolted to the upstream flange of the type girder it will, in general, require a wider wall recess if used with machinery other than the direct-acting cylinder, due to having to move the machine back from the face of the lock wall. If the machine is kept in the same position as for the hood- or vertical-shaft-type connections, the strut would have to be reduced in length, thereby creating potential interference between parts of the strut.

(c) As was previously stated, each type of connection has its advantages and disadvantages and final selection of the type to use can only be made after carefully evaluating all aspects of each individual gate, weighing cost against efficiency, maintenance, and effect on other segments of the gate or anchorage.

j. Diagonals. Each leaf of a miter gate is similar to a cantilever beam. The skin plate has such a great vertical stiffness that the diagonals are necessary only to counteract the torsional or twisting action on the leaf. (See Plate B-17.)

(1) The basic formulas and information for the design of diagonals are covered in "Torsional Deflection of Miter-Type Lock Gates and Design of the Diagonals"

(USAED Chicago 1960). (See Chapter 3 of this manual for additional information.)

(2) The stiffness of welded miter gates appears to be considerably greater in most cases than the manual indicates. While this does not affect the overall pattern of diagonal design, it should be kept in mind when selecting the values for deflection of the leaf.

(3) The diagonals may be pin connected or welded to the gusset plates. Turnbuckles or brackets on the end of the diagonals are recommended for prestressing the diagonals. Brackets are generally located on the lower end of the diagonals. However, the brackets on the newer locks in the Ohio River Division are located on the upper end of the diagonals for better surveillance. An advantage of the brackets is that no compression can be placed in the diagonal during prestressing. It is noted that the fatigue strength of the welded connection may govern the design when welding instead of pinning the diagonals to the gusset plates. Studies have shown that the most important factors which govern the fatigue strength of cyclically loaded members are the stress range and the type of details used. The AASHTO Standard Specifications for Highway Bridges, Section 10.3, allows only a stress range of 13,000 psi and 8,000 psi for 500,000 and 2,000,000 cycles, respectively, for fillet weld Category E.

(4) Strain gages installed with instant-setting cement or strain transducers should be used for determining the stress in each diagonal.

(5) The maximum stress, for temporary conditions, should not exceed 0.75 F_y. See Plate 17 for typical information on diagonals.

k. Miter and wall quoins.

(1) Miter blocks. Miter blocks are usually 8-in. by 5-1/2 in. rectangular blocks with one miter block having a concave surface with a radius of 1 ft 6 in. and the other having a convex surface with a radius of 1 ft 4-1/2 in. located at the miter ends of the leaves. These blocks are made up of 15- to 20-ft-long sections with transverse joints occurring at the center lines of horizontal girder webs. Together with the thrust diaphragms and end plates the miter blocks distribute the axial load from the horizontal girders in the vertical direction and form a contact bearing surface between the miter ends of the leaves. Jacking and holding bolts are used for temporary supports and adjustment of the miter blocks to assure full contact between leaves in the mitered position.

(2) Wall quoin. The quoin block on the lock wall is essentially the same as the miter block with the wall quoin having the concave surface with a 1-ft-6-in. radius and the quoin block on each leaf having a convex surface with a 1-ft-4-1/2-in. radius. There are two recommended types of wall quoin systems. The first system, an adjustable type, consists of a 10-in. by 3-1/2-in. bar, welded to a 1-1/4-in. by 1-ft-5-in. base plate. The base plate is attached to a vertical beam with jacking and holding bolts to facilitate adjustment and replacement. The vertical beam is embedded in second-pour concrete and transmits the quoin reaction forces into the wall. The space between the base plate and the embedded beam is filled with an epoxy filler after final adjustments have been made. The second system, a fixed type, consists of a 10-in. by 3-1/2-in. bar, welded to a vertical beam which was described previously. This type is more desirable when using zinc as a backing material because the high temperatures involved may damage the concrete.

(3) Material for quoins. Adjustable and replaceable corrosion-resisting clad steel or solid corrosion-resisting steel blocks are recommended for both miter and wall quoins. The minimum size bolts used for installation and adjustment should be 3/4 in. in diameter. Plate B-18 shows typical quoin and miter block details.

(4) Backing material. After final adjustments have been made to the miter and quoin blocks, a gap of about 1/2 in. between the end or backing plate and the blocks is filled with zinc or an approved epoxy filler. The filler layer assures a uniform transfer of the loads from the leaf into the blocks. Although epoxy is now more widely used, the contractor may be given the option of using either zinc or epoxy or the district may wish to dictate which is to be used based on their past success. In the past, epoxy was easier and safer to work with but new types of equipment for heating zinc and preheating the ends of the gate leaves have greatly reduced many objections to its use. The initial investment in the equipment needed in using zinc is expensive and the placement may be slightly more expensive, but with the life expectancy of zinc being 2 to 4 times that of epoxy, the use of zinc will be less expensive during the life of a project. Precautions should be taken to prevent leakage of either filler, and to prevent air entrapment. Application of a bond-breaking material to jacking bolts, holding bolts, and contact surfaces should be made, and the manufacturer's installation instructions should be followed explicitly. Where zinc is used, a seal weld is needed at the end joints of the blocks after cooling. Welds should be ground smooth to prevent interference with bearing surfaces. Where epoxy is used, fresh, properly stored epoxy

filler material mixed under clean and dry conditions should assure its functional performance.

(5) Cathodic protection for quoins. When carbon steel quoin and miter blocks are installed, they are bolted to the gate with zinc or Nordback in back of them. The blocks and the zinc can be protected with cathodic protection. As a minimum, the sides of the blocks can and should be painted. The miter and quoin faces are protected with protective potentials in the same manner as the gates.

l. Seals. Rubber seals should be installed on the bottom of each leaf to seal the gate to the miter sill. Various types of seals have been used by the different districts and divisions with varying degrees of success. The seal should give a reasonable degree of watertightness but some leakage is to be expected. Excessive leakage is objectionable when the lower portion of the gate is exposed.

(1) Where a large temperature range is encountered the 4-in. round rubber seal appears to be satisfactory. This type of seal allows for the effective shortening or lengthening of the leaf, which causes the leaf to change positions with respect to the sill. This seal allows the upper pool to force it against the gate leaf, eliminating possible vibration. The curved section around the pintle generally utilizes the J-type seal, the shape and size of the 4-in. diameter rubber seal not being conducive to sharp bends. The sill concrete is second pour around the embedded portion of the seal. See Plate B-21 for details.

(2) Where the temperature range is such that the variations in leaf length are small, the so called "Porkchop" type seal has been used. The sill angle for this type of seal is in second-pour concrete, with all adjustments made before placing the second pour. This type of seal also reduces the probability of vibration encountered with the J-type seal. See Plate B-21 for details.

(3) Although the seal arrangements described above have provided satisfactory service in the past, they are subject to vibration and damage from debris and are not recommended for new construction.

(4) The seal detail, Section A-A, shown in Plate B-22, eliminates vibration problems caused by changes in the length of the leaves due to temperature fluctuations. Inherent in its higher location and orientation, it is also less susceptible to damage from debris and provides positive sealing under unbalanced head

conditions. Therefore, this type of seal is recommended for new construction.

(5) Where there are large amounts of debris, drift, and large rocks tumbling along the bottom, such as in the shallow rivers of the Upper Mississippi River System, a successful method of sealing has been attaching the J-seal to the embedded metal in the sill. This method of sealing is not easily damaged, is reliable, and can be easily replaced. See Plate B-22 for details.

(6) Above the top girder, J-type seals are used to seal the leaf to the top of the bulkhead plate. See Plate B-23 for a typical detail.

m. Miter guide. The miter guide is used to bring both leaves of the gate into the mitered position simultaneously, thereby facilitating seating of the miter blocks. The guide assembly may be located on the upstream side of the top girders or on top of the top girder web of each leaf. The miter guide is made up of two major components, the roller, mounted on an adjustable bracket, and the two-piece, adjustable, v-shaped contact block with its support. The roller bracket and the contact block are connected to their supports with a series of push-pull bolts to permit field adjustment. Steel shims or epoxy filler may be used to secure the miter guide components in their final positions. The height of the contact block should be greater than the length of the roller. The roller should be equipped with a bronze bushing and a suitable greasing arrangement. (See Plates B-19 and B-20 for typical details.)

n. Walkway. Each leaf of all miter gates should be equipped with a walkway such that when the gate is mitered a continuous walkway is formed across the top of the gate. The walkway should have a width of 4 ft 0 in. back-to-back of support angles, with the top of the walkway flush with the top of the lock wall. The vertical legs of the support angles will act as a toe board for the walkway. (See Plate B-19.)

(1) The angle is supported by vertical stiffeners and the bulkhead plate on the downstream side and by structural tees acting as columns on the upstream side. The tees should be placed above the vertical diaphragms and girder web stiffeners as far as practical. The design load for the walkway should be 100 pounds per square foot (psf).

(2) Steel grating shall be type II and hot dipped galvanized after fabrication, with a minimum depth of 1-1/4 in. The ends of all grating shall be banded with bars the same size as the bearing bars. Panels shall be made in convenient sizes for installation and removal, with a minimum of four clips per panel.

(3) Other materials may be used for the walkway surface on top of or in place of grating with an adequately designed support system. These materials should have adequate load-carrying capacity if used in place of steel.

(4) The end of the walkway adjacent to the lock wall should be made on a radius, usually 4 ft 5 in., from the center line of the gudgeon pin to the outside edge. This section should be hinged at the edge of the bulkhead plate. The outer edge of the radius is supported by an angle on the lock wall and an angle that is an integral part of the grating system over the anchorage recess.

(5) Handrail should be designed to meet OSHA Standards which require it to support a 200-pound (lb) concentrated load applied at any point in any direction. For normal installations and post spacing, 2-in.-diameter extra strong pipe post with 2-in. standard pipe rail, or equivalent aluminum if economy dictates aluminum for the lock walls, will be required. The railing should be removable and made in convenient size panels, with handrail located on both sides of the walkway. For additional information and guidance on railing design see the ASSHTO Standard Specifications for Highway Bridges.

o. Bridgeway. Instead of a walkway, a maintenance bridgeway may be provided over and supported by the lower miter gates to accommodate a mobile crane, thereby eliminating the frequent need for a floating plant for many maintenance and repair operations. The roadway and supports may be designed for the wheel loads of a 20-ton-capacity mobile crane without impact. The allowable working stresses will be in accordance with current AASHTO specifications.

p. Fenders and gate stops. All miter gates should be equipped with a system of bumpers and fenders to protect the gate from impact and to prevent damage by passing tows when the gate is in the recess. Four basic types of fender systems have been used on gates in the past, with the systems consisting of wood, rubber, metal, and a combination of rubber and metal.

(1) The all-metal type, normally made of pipe, tubing, or curved plates, offers the advantages of ruggedness and minimum damage while in use but has the disadvantage of having very little energy-absorbing capacity. Where welded directly to the girder flanges, impact is

transferred through the girder web to the operating strut, anchorage, and pintle.

(2) A combination fender, made of pipe or a curved plate, mounted with rubber pads between the metal contact surface and the girder flanges gives a more desirable energy-absorbing capacity but is a more complex and expensive system.

(3) The all-rubber fender system offers the highest degree of impact protection for the gate but has some disadvantages such as passing tows tending to tear the rubber fender from the gate and the increased cost of the system; however, low-friction butyl rubber fenders are being used successfully and may prove to be a viable alternative to timber based on a life-cycle cost.

(4) When all aspects of the basic system are considered, timber fender systems appear to be the most desirable. Timber offers a reasonable degree of resiliency for gate protection, is rigid enough to resist the sliding forces from passing tows, and is normally readily available, and in most cases, is considerably more economical than the other systems. When timber is used, white oak is generally the more desirable species if available locally. When white oak is unavailable, pine timber is an acceptable substitute. The size of timber of either white oak or pine should generally be 10 in. by 10 in. (S4S), pressure treated with creosote if pine and untreated if white oak.

(5) The fender system should be installed on the downstream flanges of all horizontal girders subject to an impact loading. Generally, this extends from a point at or slightly below the minimum pool up to a point approximately 6 ft above the maximum pool to be in the lock during operation. Consideration should be given to placing fenders 2 ft on center vertically in areas where heavier tows are likely to cause considerable damage to gates. Vertical beams spanning between horizontal girders should be used to support the extra fenders. Fenders should be fastened to the flanges of horizontal girders with a minimum of 3/4-in.-diameter bolts, 2 ft on center and alternating sides, vertically, of the flange, with the head of all bolts recessed a minimum of 1 in. to prevent passing barges and boats from catching the bolt heads. If rubber fenders are used, bolt heads should be recessed as much as practical to allow for compression of the fender and prevent the bolts from being caught by passing tows.

(6) Bumpers are selected by applying the same criteria as those for fenders. Where ice buildup in recesses is not a problem, bumpers are fastened to the wall of the recess to cushion any impact between the gate leaf and the wall. If ice buildup in the recess is a problem, bumpers can be mounted on the gate leaf. Timber bumpers are generally made of 12-in. by 12-in. (S2S) white oak. Bumpers are placed so as to strike the leaf near the end vertical diaphragm at the miter end, on the center line of the horizontal girders. The minimum number of bumpers used should be one for each of the top two girders and one for each of the bottom two girders. On high gates, it may be desirable to also place bumpers for some of the intermediate girders. The length of the bumpers should be approximately 2 ft on the impact face. Each bumper should be fastened to the wall of the recess with a minimum of two 3/4-in.-diameter bolts, with the ends of the bolts recessed a minimum of 1 in. to prevent the bolts from striking the gate.

q. Gate latches. Latches should be provided to hold each gate leaf in the recess against temporal hydraulic loads and in case of an emergency. Due to the vertical stiffness of the leaf a latch at the top of the leaf is normally sufficient. Where the lock is used as a floodway during high flows and where required by temporal hydraulic loads, additional latches, located near the center of the leaf, vertically, or near the lower miter corner of the leaf, may be required. Latches should be so constructed that the leaf is held snug against the bumpers so the potential vibration is kept to a minimum. Also see automatic gate latches, paragraph 2-5*f*(3). A latch or tie should also be provided to tie the leaves in the miter position, again with the ability to pull the leaves together so as to reduce the probability of vibration. See Plates B-24, B-25, and B-26 for suggested latch details.

r. Embedded metals. The items normally included as embedded metals are miter sill angle, pintle base, wall quoin and support members, embedded anchorage, and gate tieback. With the exception of the pintle base, all items are usually made of structural steel, with some items, such as the wall quoin block, having a corrosion-resisting surface in some instances. All items have been discussed previously except the sill angle. The sill angle is placed in second-pour concrete, with provision for adjustment to the gate leaf, with all adjustments being made before the second pour is placed. See Plates B-21, B-22, and B-32 for a suggested plan of a sill angle arrangement.

s. Cathodic protection. Two basic methods of cathodic protection are the sacrificial anode method and the impressed current method with the impressed current system being the most efficient. Impressed current is required to protect the large areas between the horizontal girders and the skin plate of the gate. The anodes of the

system are placed between the horizontal girders, with the vertical wiring passing through holes in the girder webs. This makes the system much less susceptible to damage from traffic or debris. In most cases, metallic conduit and some angle iron are required to protect the cathodic protection anodes. (See CW-16643 for impact protection.) See Chapter 7 of this manual for additional information.

2-2. Miter Gates, Horizontally Framed-Arch Type

The analysis of the arch gate is similar to that of the straight horizontally framed type gate. As with the straight gate, the general analysis for the arch neglects the vertical stiffness of the gate leaf and skin plate. Plate B-27 shows the geometry and forces on the arch rib. The longitudinal axis of the horizontal rib girder approximates the "pressure or thrust line" from the loading conditions; thus the magnitude of the bending moment in the ribs, determined from the eccentricity of the axial load to the ribs' axis, is a minimal value. The skin plate for this gate is designed as a continuous member. The intercostals of the gate shown in Plate B-28 do not come in contact with the skin plate. The primary function of the intercostals is to serve as vertical diaphragms. Design of the other elements of the arch gate leaf and anchorages is covered under paragraph 2-1. Plates B-28 and B-29 show horizontal rib girder and diaphragm layout.

2-3. Miter Gates, Vertically Framed

Horizontally framed gates provide a more rigid structure and are usually economically comparable to vertically framed gates. While vertically framed gates should not be used for new construction, this manual covers vertically framed gates to provide information because of their use in existing structures.

a. Reactions. Due to the basic framing plan of a vertically framed gate, with the horizontal girder supporting the upper end of all vertical members, the reaction of the horizontal girder is similar to the reaction of a girder in a horizontally framed gate. The girder in each type of gate acts as a segment of a three-hinged arch, with the end reactions and related forces being the same in both cases. The designations R, N, P_1, and P_2 are the same for both horizontally and vertically framed gates. The lower ends of all vertical members are supported directly by the sill, with the bottom girder acting to transfer the concentrated loads into a uniform reaction on the sill.

b. Skin plate and vertical beams.

(1) Skin plate. Existing vertically framed gates may have either the conventional-type skin plate, generally located on the downstream side of the leaf, or a skin plate composed of buckle plates fastened to the upstream flanges of the vertical beams and framing into the webs of the vertical girders. Although buckle plates are still in use on existing gates, they are no longer used for new construction. In determining the location of the skin plate for a vertically framed gate, consideration should be given to the problems of uplift and silting. While the skin plate located on the downstream face of the gate eliminates uplift, the maximum area is exposed for silt accumulation. The reverse is true for the skin plate located on the upstream face of the gate. The more desirable skin plate location will have to be determined for each site, weighing the problem of uplift against the problem of silting.

(a) The analysis of flat panels of skin plate is the same as discussed for horizontally framed gates, with the desirable panel shape being approximately square. (See Plate B-2 for additional information.)

(b) Intercostals are required for flat skin plates, spanning horizontally between vertical beams and between vertical beams and vertical girders. The criteria for intercostal spacing and design are essentially the same as those for horizontally framed gates. See Figure 2-3 for additional information on design.

(2) Vertical beams. Vertical beams span between the top and bottom girders, supporting the buckle plates on their upstream flange or the flat skin plate on the downstream flange. The vertical beams are assumed to be simply supported top and bottom, with simple moment and shear dictating beam size. Spacing of the vertical beams is determined largely by load and support requirements for the skin plate system with a normal location being at the quarter points between vertical girders.

(3) Vertical girders. Vertical girders are vertical members that function as vertical beams and at the same time serve as support members for the top and bottom girders. The vertical girders are spaced so that practically all vertical forces caused by the diagonals are carried by the vertical girders. The most effective panel for diagonals is when the height is no more than 1.50 times the width. The vertical girders and the bottom girder are normally the same depth so as to

simplify framing and make the bottom girder flanges more directly effective in taking the components of the diagonals. The stability of the girder flanges under these components should be verified, assuming the flanges to act as columns. Webs of the girders are normally determined by minimum thickness rather than by shear requirements (the minimum thickness of all material should be 3/8 in.) and should be checked for stiffener requirements.

c. Horizontal girders.

(1) Top horizontal girder. The top horizontal girder is designed to withstand a simultaneous load of water force and boat impact. The water force is applied as concentrated loads by the vertical beams and girders; the boat impact load is as described in paragraph 2-1*b*(1), acting directly on the top girder. The top girder design is essentially the same as that for the girders in a horizontally framed gate; the symbols W, N, R, P_1, and P_2 are the same for both types. The reaction of the top girder is transmitted through steel bearing blocks at each end of the girder. These blocks are similar to the bearing arrangement for horizontally framed gates, having the same convex and concave faces and the same adjustment. The bearing blocks may be of cast steel or a built-up weldment; the weldment has the advantage of being more easily obtained in the event replacement is necessary. The girders should be designed to withstand water load and basic stress or the combined water and boat impact with an allowable 1/3 overstress.

(2) Bottom horizontal girder. Under normal conditions, the bottom girder does not function as a girder but rather as a member to transfer the concentrated vertical beam and girder loads into a uniformly distributed horizontal force on the sill. For most gates, the bottom girder center line is located approximately 4 in. below the top of the sill to provide sufficient bearing surface between the girder and the embedded metal. The girder is also checked for sufficient capacity to carry the reaction from any vertical beam or girder to adjacent beam or girder points if irregularities or obstructions between the sill and bottom girder prevent bearing at a vertical beam location. The minimum effective length for this should be twice the vertical beam spacing. When the leaf is not in the mitered position, the bottom girder acts as a column, having an axial load created by the dead weight of the leaf. The downstream flange of the bottom girder is designed to distribute vertically the bearing load on the sill, which may require stiffener plates to support the flange. If the skin plate is not a flat plate on the downstream face of the leaf, the downstream flange of the

bottom girder is subjected to vertical bending due to the hydrostatic uplift on the bottom of the leaf with the web of the girder acting similar to a skin plate. Adjacent to the pintle, the bottom girder should be checked for the horizontal reaction of the pintle. The depth of the bottom girder also influences the depth of the vertical girders and has a direct relation to the stiffness of the leaf, this being determined by the distance between sets of diagonals or, in the case of a flat skin plate, the distance between the skin plate and diagonals.

d. Diagonals. Design of the diagonals for a vertically framed gate is essentially the same as that for a horizontally framed gate (see USAED, Chicago 1960). Most existing vertically framed gates have diagonals on both the upstream and downstream faces, with buckle plates located between the two sets. If a flat skin plate is used on the downstream face of the leaf, diagonals are required only on the upstream face, with the skin plate taking all the vertical shear from dead load. The number of panels of diagonals used on vertically framed gates depends on the spacing of vertical girders. The panel size of height equals 1.50 times the width is desirable, but should not in itself be the only consideration for vertical girder spacing, which sets the panels for diagonals. Usually leaf dimensions are such that three sets of diagonals on a leaf face are commonly used. Due to flexibility of a vertically framed gate turnbuckles are recommended on all diagonals to allow for easier adjustment at a later time. See Chapter 3 and Plate B-17 for additional information on design of diagonals.

e. Wall quoin. The wall quoin of a vertically framed gate, similar to the wall quoin of a horizontally framed gate, serves to distribute the girder reaction of the horizonal girder. The main difference in the two types is the vertical height of the reaction bearing area. The wall quoin of a vertically framed gate is normally in the order of 2 ft-0 in. high and 1 ft-8 in. wide. The quoin block may be made of cast steel or a built-up weldment, with weldment generally being more readily available in the case of replacement. The block is made to fit the quoin block of the girder and is attached to an embedded beam to distribute the force to the concrete. The beam should be of sufficient size to maintain bearing on the concrete to approximately 600 psi or less, so that cracks in the concrete around the corner of the gate recess will be kept to a minimum. The beam is generally placed horizontally in first-pour concrete with the bearing being detachable with provisions for adjustment.

f. Top anchorage and gudgeon. The design of the anchorage elements is similar to the design of the

anchorage for horizontally framed gates. Frequently the same anchorage is used for both types when a lock has an upper gate vertically framed and a lower gate horizontally framed, where the small difference in materials generally is not enough to offset the savings of making two identical sets. The gudgeon pin and hood are both similar to those for horizontally framed gates, with the exception that the pin hood of the vertically framed gate increases the moment on the vertical beam adjacent to the quoin girder. This gives a combined loading of water plus the forces from the pin hood on this particular vertical beam.

g. Strut connection. The strut connection for vertically framed gates is essentially the same as that for horizontally framed gates, with the exception that the horizontal girder for vertically framed gates carries all the strut force whereas vertical diaphragms on horizontally framed gates distribute the load to the first two and sometimes the first three horizontal girders.

h. Pintle and pintle anchorage. The design of the pintle for vertically framed gates is the same as that for horizontally framed gates, using the same procedures and materials. The design of the pintle base for vertically framed gates is essentially as described for horizontally framed gates, with similar bases being required for horizontally framed leaves consisting of five or six girders and vertically framed leaves. Relatively speaking, horizontal forces on the pintle base are greater for the vertically framed gates and the smaller horizontally framed gates. Unlike horizontally framed gates, the pintle socket, or center of pintle, is generally located on the center line of the bottom girder. See Plate B-30 for information relating to the seal between leaf and pintle base.

i. Bottom sill. The bottom sill for vertically framed gates, unlike the sill of horizontally framed gates, receives a significant amount of water force applied to the gate. The embedded metal segment of the sill should provide an adequate bearing and sealing area and limit bearing on the concrete to approximately 300 psi or less. Anchor bolts to hold the embedded metal are set in first-pour concrete with the embedded metal placed in second-pour concrete. See Plate B-32 for a typical sill layout.

j. Seals.

(1) Wall seals. The wall seal of a vertically framed gate consists of an embedded channel with a cladding of corrosion-resisting material on the exposed sealing surface. This channel is embedded in first-pour concrete,

with the rubber J seal on the leaf being adjusted to the sealing surface of the channel. (See Plate B-30.) The seal on the gate leaf is composed of a rubber J seal attached to a vertical plate which is an extension of the web of the vertical quoin girder. The flange of the quoin girder is made of one plate, with the web extension welded to the outside of the flange. An angle between the rubber seal and the web extension allows for adjustment of the seal.

(2) Miter seal. The miter seal consists of a vertical plate on one leaf and a conventional J seal on the other leaf, placed so that the water pressure forces the rubber seal against the vertical plate. Below the web of the bottom girder two rectangular rubber blocks, one on each leaf, form the seal between the vertical J seal and the sill.

(3) Bottom seal. The bottom seal of vertically framed gates is formed by the contact between the bottom girder and the embedded metal of the gate sill. A metal bearing plate is attached to the downstream flange of the bottom girder and this also acts as a seal plate. At the end of the leaf adjacent to the pintle, a solid rubber block seal attached to the leaf is used between the leaf and pintle base. (See Plates B-30 through B-32 for additional information.)

k. Mitering device. The mitering device is essentially the same for both vertically and horizontally framed gates with the same basic dimensions and materials used for both types. See Plates B-19 and B-20 for a typical mitering arrangement.

l. Walkways. Walkways for vertically framed and horizontally framed gates are essentially the same, using the same basic dimensions and design criteria. See paragraph 2-1*n* on walkways for horizontally framed gates and Plate B-19 for additional information.

m. Fenders and gates stops. The same protection system and gate stops are used for both vertically and horizontally framed gates. See paragraph 2-1*p* for more information.

n. Gate latches. Gate latches for both vertically and horizontally framed gates are essentially the same. While there may need to be a slight variation in the method of attaching the latching unit to the leaf the same general method should be used for the vertically and horizontally framed gates.

o. Embedded metals. The normal items included in the category of embedded metals are the embedded top

anchorage, quoin bearing, pintle base, and miter sill embedded metal. All items are essentially the same as those for horizontally framed gates except the miter sill embedded metal. All other items have been discussed in the paragraphs on horizontally framed gates and in previous sections for vertically framed gates. While the sill embedded metal is similar for both horizontally and vertically framed gates, the sill for vertically framed gates is designed to receive the gate reaction and distribute this force to the concrete. As previously stated, the sill embedded metal serves two functions, acting as a bearing surface and as a sealing surface. The embedded metal is placed in second-pour concrete; the supporting anchor bolts are set in first pour. All adjustments between gate and sill are made before placing the second-pour concrete. See Plate B-32 for a suggested sill layout.

p. Cathodic protection. The cathodic protection systems of both vertically and horizontally framed gates are essentially the same. The location and number of anodes may vary but the method and components are the same for both types of gates. For further information, see Chapter 7.

2-4. Erection and Testing, Miter Gates

a. Miter gates, both horizontally and vertically framed, should be completely shop assembled, if size permits, with adjoining pieces fitted together to ensure satisfactory field connections. The tolerances should not exceed 1/16 in. for individual members up to 30 ft in length and not more than 1/8 in. for members over 30 ft in length. Structures made from two (2) or more members should not deviate from the overall dimension by more than the tolerance for any one member. Rubber seals should be fitted and assembled to the gate leaf in the shop, with holes drilled to match the seal supports on the gate leaf and then removed for shipment. Before disassembly of the leaf each piece should be match-marked to facilitate erection in the field.

b. The bottom pintle casting shall be adjusted to proper elevation and position and then properly concreted in place before erection of the leaf. The bearing surface of the pintle and bushing should be thoroughly cleaned and lubricated before setting in place. Consideration should be given to using temporary concrete pedestals to support the leaf, with a minimum of two pedestals per leaf and allowing the pintle to support the quoin end of the gate leaf.

c. Care should be taken to ensure that the parts of the gate leaves are in correct alignment before any field welding is commenced. All necessary precautions should be taken to prevent distortion of the leaf as a whole or of any of its components. Each unit should be accurately aligned so that no binding in any moving parts or distortion of any members occurs before final connections are made.

d. After completion of the leaf, the top anchorage links should be installed and adjusted so that the center of the gudgeon pin is in vertical alignment with the center of the pintle.

e. After diagonals have been prestressed and final adjustments have been made to the anchorage, the leaves shall be mitered and securely held in this position while the contact blocks at the quoin and miter ends are brought into firm contact by adjusting the bolts behind the blocks. After adjustment of the blocks, the leaves should be swung out and zinc or epoxy filler poured between the seal blocks and the end plates of the leaves. If zinc is the option selected by the contractor, blocks and plates adjacent to the zinc shall be preheated to a temperature between 200 and 250 deg F, immediately preceding the pouring to prevent the zinc from cooling before it can fill the area behind the blocks. The pouring temperature of the zinc shall be maintained between 810 and 900 deg F to avoid volatilizing or oxidizing the metal and to ensure that it will fill the area behind the blocks. Pouring holes should be located 2 to 3 ft apart. If the alternate backing of epoxy is selected, the material should meet the properties set forth in paragraph 2-1*k*(4).

f. After a gate leaf is erected, diagonals prestressed, and miter and quoin blocks adjusted and set, each leaf should swing without interference of the quoin blocks until, as the gate is mitered, the quoin block on each leaf makes tight contact with the one on the lock wall. After final adjustment of blocks and seals, the gate leaf should swing freely and any point on the moving structure should remain in a horizontal plane throughout the entire range of movement. Past experience indicates that 1/16 in. on the smaller locks to 1/8 in. on the 110-ft or larger locks can be allowed as maximum variance from the horizontal plane and not have any adverse effect on the gate, although every effort should be made to keeping the leaves in a horizontal plane.

g. After completion of the gate, including prestressing of the diagonals, installation of all seals, and all

adjustment, the gate leaves should be swung through a sufficient number of opening and closing operations to assure that the leaves are in true alignment and that necessary clearances have been provided. After this trial operation the leaves should be swung out and the second-pour concrete placed in the sill and wall quoins.

h. The miter guide should be installed after the trial operation and second-pour concreting has been completed. The guide bracket and roller bracket assemblies should be mounted on their respective leaves with the gate in the mitered position. Adjustments should be made to the brackets so that either leaf may be mitered or opened without disturbing the other leaf.

i. The final test on the gate should consist of operating the gate under power, by means of the permanent operating machinery, first during the unwatered condition and then using available headwater and tailwater. The leaves should be operated through their entire travel a sufficient number of times to indicate that all parts and equipment are in proper operating condition. The workmanship in fabrication and erection of the gates shall be such that, when mitered, they will form a watertight barrier across the lock under all ranges of head, except for minor negligible leakage at the miter, sill, or quoin.

2-5. Operating Machinery

a. General description of linkages and components. Four different types of miter gate operating machines have been frequently used. The Panama Canal linkage, which has no angularity between the strut and sector arms at either the open or closed positions of the gate, is shown in Figure 2-6. The Ohio River linkage, having angularity between the strut and sector arms at both the open and closed positions, is shown in Figure 2-7. The Modified Ohio River linkage has angularity between the strut and sector arms at the recess or open position and no angularity at the mitered or closed position. This linkage is shown in Figure 2-8. A direct connected cylinder has been used on some 84-ft-wide locks and consists of a hydraulic cylinder and rod connected to a pin on the gate and a pin on the lock wall, the piston force being transmitted directly from the piston rod to the gate. This linkage is shown in Figure 2-9.
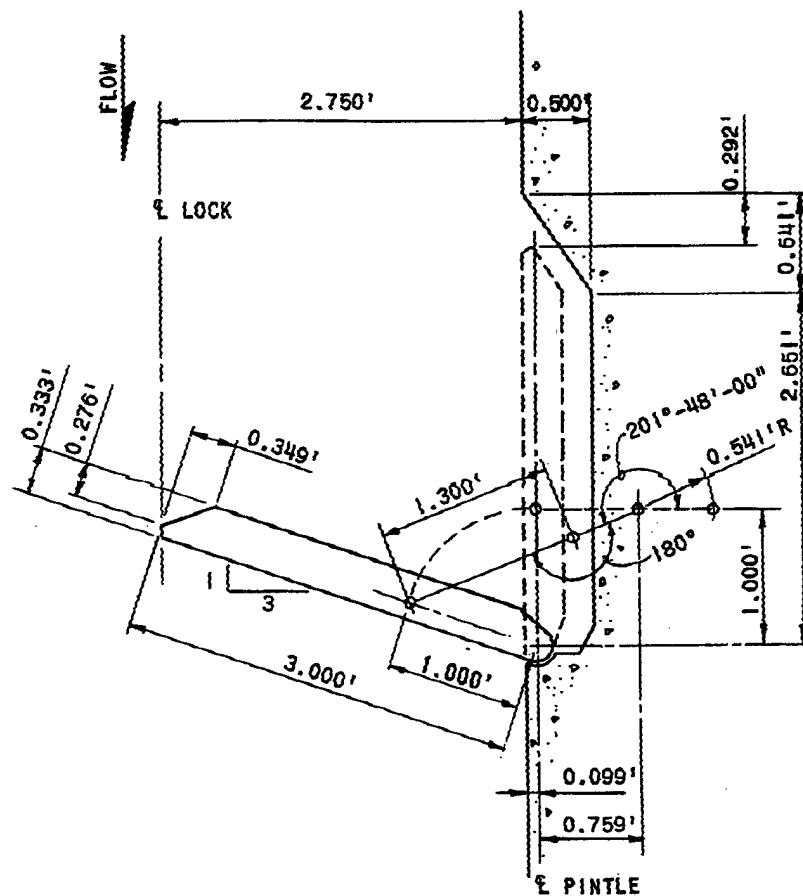
(1) Panama Canal linkage. The Panama Canal linkage has been used primarily where electric motor operation was feasible, that is, at locations where high water will not overtop the lock wall. The operating machinery for this linkage generally consists of a high torque, high

slip a-c motor driving the gate through two enclosed speed reducers, bull gear, sector arm, and spring-type strut. This linkage will permit the gate to be uniformly accelerated from rest to the midpoint of its travel and then uniformly decelerated through the remainder of its travel, thus eliminating the need for elaborate motor speed control. This is accomplished by locating the operating arm and strut on "dead center" when the gate leaf is in both the open and closed positions. The strut must be located at a higher elevation than the sector arm in order to pass over the arm and become aligned for dead center position when the gate is fully open. Special consideration should be given to the design of this eccentric connection between the strut and sector arm. An assembly layout of the Panama-type linkage is shown in Plate B-47.

(2) Modified Ohio linkage. The Modified Ohio linkage is similar to the Panama type except that the dead center alignment is attained only in the gate fully closed position. With the Modified Ohio linkage, the strut and sector gear are located at the same elevation, thus eliminating the eccentric strut connection but preventing the linkage from attaining the dead center position with the gate recessed. The operating machinery for this linkage has been built either for electric motor drive as with the Panama linkage or hydraulic operation as with the Ohio River machine. An assembly layout of the Modified Ohio linkage with electric motor drive is shown in Plate B-48.

(3) Ohio linkage. The Ohio linkage consists of a hydraulic cylinder, piston rod, toothed rack meshed with a sector gear, and a sector arm, the spring-type strut being connected to the gate leaf and sector arm. A typical machine is shown in Plate B-49.

(4) Direct connected linkage. Another type of machine is the "Direct Connected Type." It consists of a cylinder mounted in a gimbal bracket and located in a recess on the lock wall with the piston rod connected directly to a bracket on the gate. The kinematics of this linkage is such that it is necessary to control the acceleration of the gate by use of a variable volume pumping unit instead of relying on the mechanical advantage of the linkage to accomplish this. Since the piston rod is used as a strut, it is generally a little larger in diameter than the rod of the Ohio-type machine. This larger rod increases the ratio of time of opening to time of closing since the net effective cylinder volume on the rod end is smaller than the volume on the head end. This variation in opening and closing times can be eliminated by use of

Figure 2-6. Panama Canal linkage (USAEWES 1964)
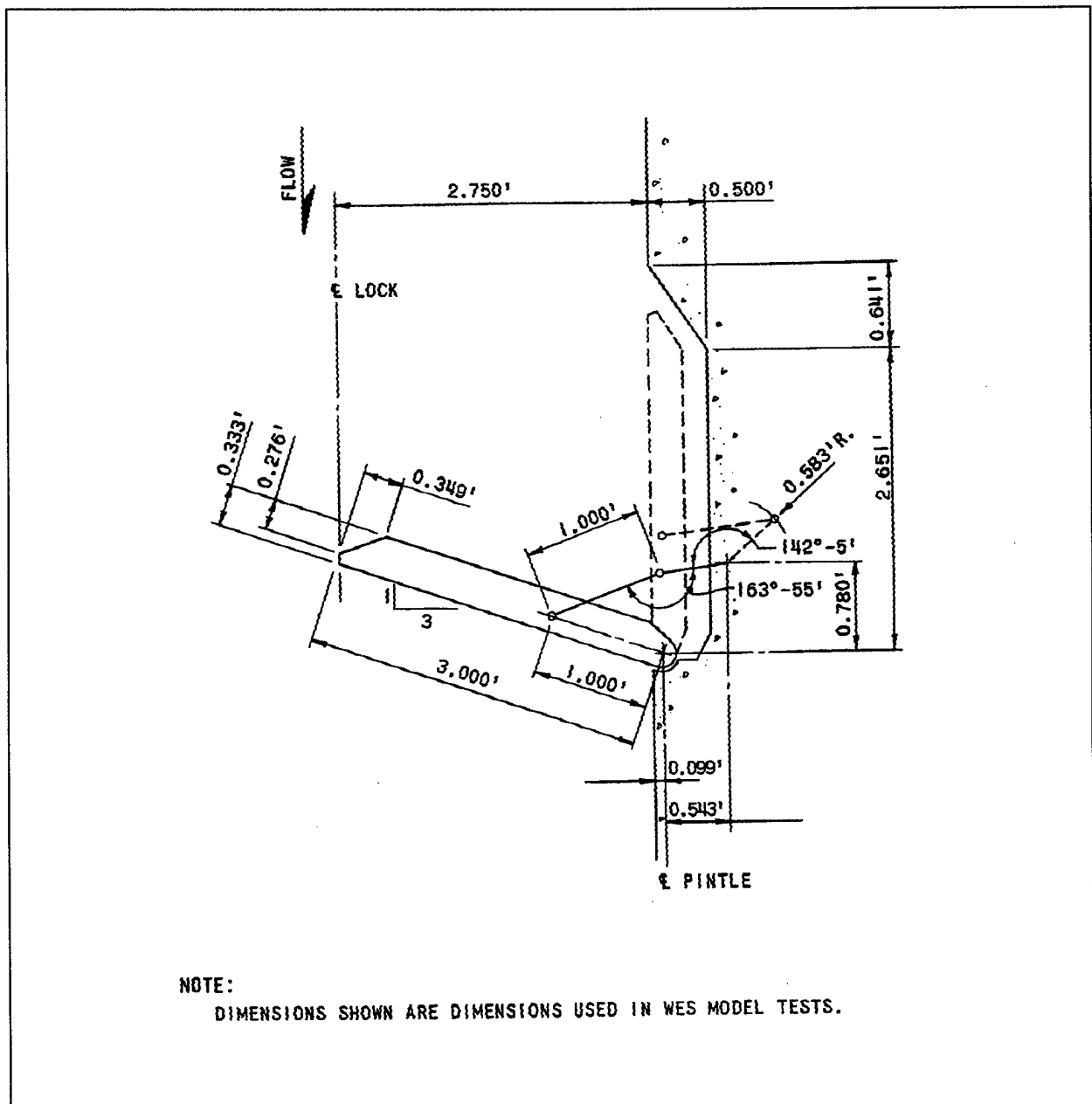
Figure 2-7. Ohio River linkage (USAEWES 1964)

NOTE:
DIMENSIONS SHOWN ARE DIMENSIONS USED IN WES MODEL TESTS.
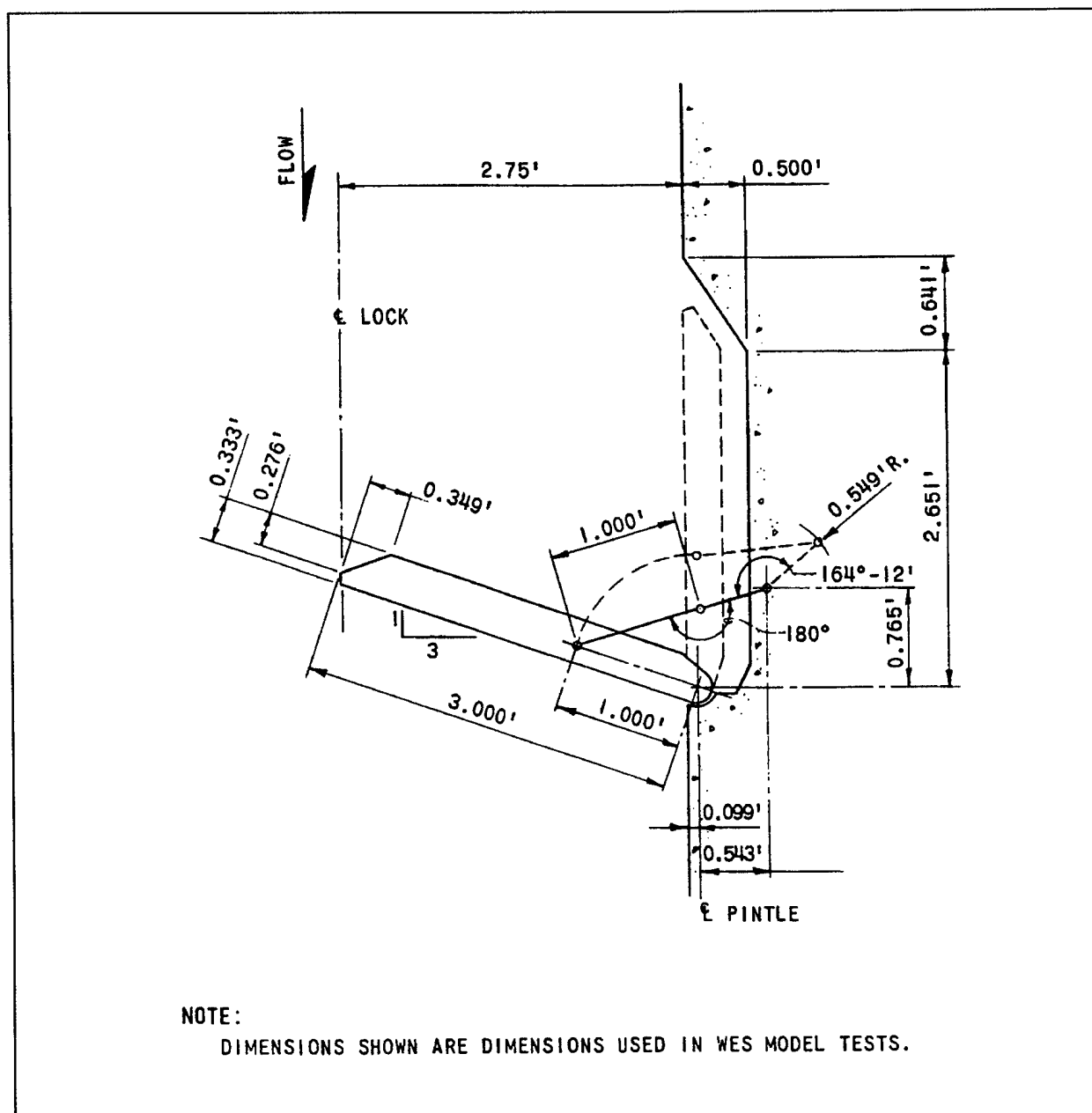
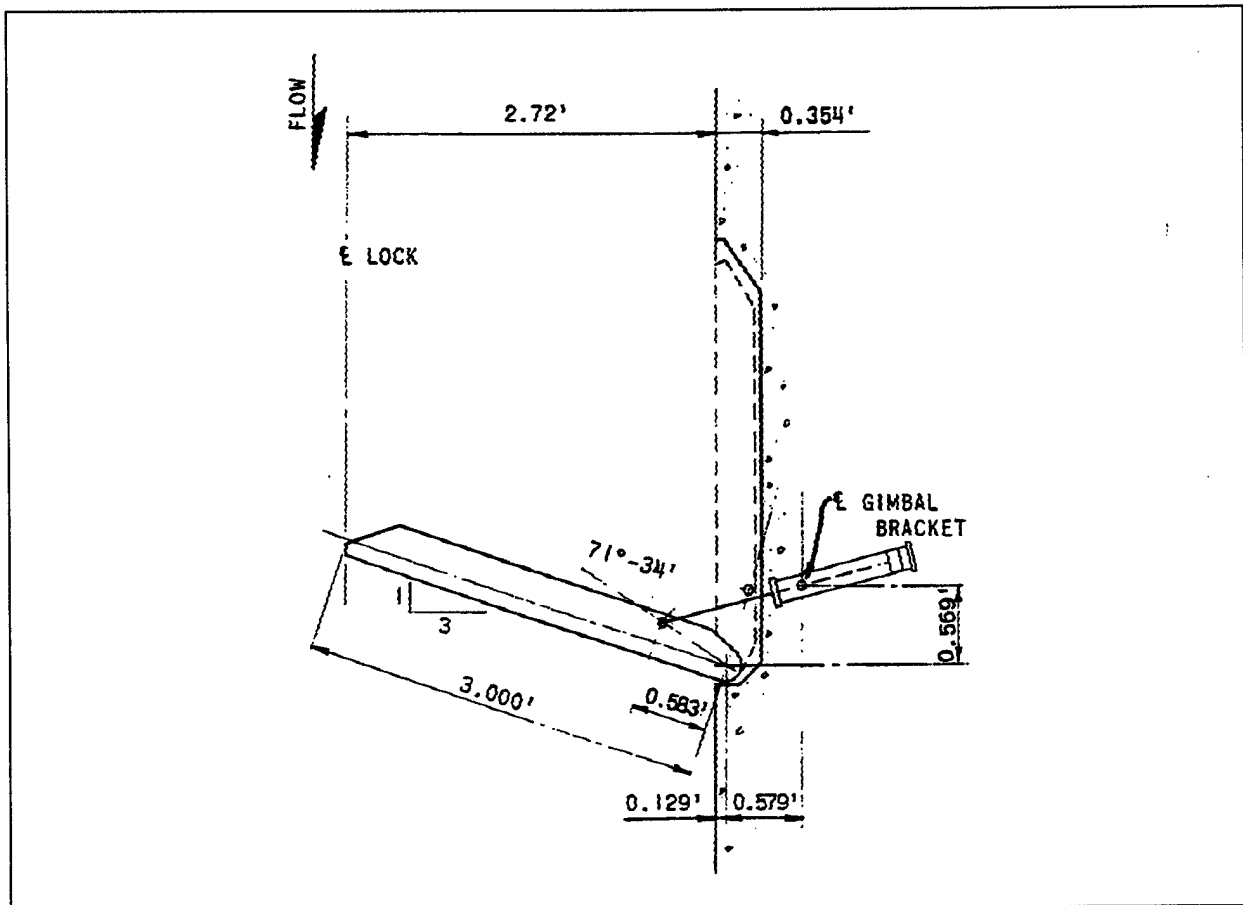Figure 2-8. Modified Ohio River linkage (USAEWES 1964)

Figure 2-9. Direct connected linkage

variable volume flow control valves or by use of a regen-
erative circuit along with a cylinder in which the rod area
is about one-half the piston area. The arrangement of the
direct connected type machine is shown in Plate B-50.
The direct connected type of machine has been used
satisfactorily on 84-ft-wide locks in the U.S. with locks
up to nearly 100 ft and 110 ft wide in Europe. The use
of the direct connected cylinder on locks 110 ft wide
now appears to be a viable option; however, an in-depth
design analysis should be made for each application
considered. Experience has shown that the direct con-
nected machine costs approximately 30 percent less than
the conventional Ohio-type machine when used on locks
up to 84 ft wide.

(5) Recommended linkage. The Ohio River or direct
connected linkage is probably the most satisfactory type
to use with hydraulic cylinder operation. With the Ohio
River and Direct Connected linkages, load analysis for all

components is possible. Overloads due to surges or
obstructions are carried through the piston and converted
to oil pressure which is released through a relief valve.
In this way, all machinery component loads can be deter-
mined based on the relief valve setting. This is also true
for the Modified Ohio linkage except at the mitered
position. As this linkage approaches the mitered posi-
tion, the sector arm and strut approach the dead center
position. Should an obstruction be encountered at this
time, the force in the strut becomes indeterminate.
Although this linkage provides restraint against condi-
tions of reverse head in the dead center position, it must
be designed with an easily repaired "weak link" to limit
the maximum loads that can be placed on the machinery
components. The Modified Ohio River linkages on some
locks have yielded unsatisfactory results, and these have
been converted to Ohio River linkages. The Ohio River
linkage offers several obvious advantages due to its
unique geometric configuration relating to the

acceleration and deceleration of the miter gates. The disadvantages of this system are wear, bearing forces, and mechanical inefficiencies associated with the geared rack, sector gear, sector arm, and strut. Ohio River linkages have recorded a service life of over 50 years on many locks, with good reliability and a minimum of maintenance.

(6) Struts. Two types of struts have been used for the above-mentioned machines. One type utilizes several nests of helical coil springs installed into a cartridge and attached to a wide flange structural steel fabricated member. The springs, when compressed, act as a shock absorber to soften the loads transmitted to the operating machinery. In the case of electric-motor-operated machines, the compression in the springs permits the operation of a limit switch to cut off current to the motor when the gates are mitered or recessed. The switch also serves as a limit switch to protect the machinery against the possibility of extremely high loads which might occur if an obstruction is encountered when the strut approaches dead center in either direction. The limit switch is set to open the motor circuit at a point immediately preceding the maximum spring compression in the strut. This type of strut is shown in Plate B-51. Another type of strut utilizes a spring cartridge housing and tubular steel strut. Ring springs are used in the spring cartridge to provide the necessary deflection. Excessive maintenance and repair costs have occurred with the use of this type of strut. In addition, ring springs are available only from one manufacturer. Use of the ring-spring-type strut is not recommended. Recently, Belleville springs have been utilized in struts and appear to function satisfactorily. The Belleville spring strut is shown in Plates B-52 and B-53.

(7) Sector gear anchorage. The sector gear support and anchorage is one of the more critical items to be considered in the design of miter gate machinery. For proper machine operation and long component life, the sector gear must be maintained in rigid and proper alignment. The recommended arrangement consists of a sector base anchorage, sector base support, and a sector base. The sector base anchorage is a welded steel frame embedded deep in the concrete which provides anchorage and alignment for post-tension rods. The sector base support is a heavy, rigid, welded steel member which is anchored to the concrete by the post-tension rods. The sector base is a heavy steel casting which is bolted to the sector base support and contains the sector pin on which the sector gear turns. The sector gear pin should be restrained to prevent rotation in the sector base. The design is such that the final post-tension rod force is enough to resist the horizontal sector pin load by friction between the concrete and sector base support. In addition, compression blocks are welded to the bottom of the sector base support to provide additional resistance to horizontal motion. Details of this anchorage are shown in Plate B-49.

b. Design criteria.

(1) Design loads.

(a) Normal loads. Gate operating machinery should normally be designed to conform to the following criteria: Operating loads on the miter gate machinery should be derived by hydraulic similarity from test data obtained from model studies. The model study available for design is included in Technical Report 2-651 (USACE-WES 1964). (This was the last study made by WES on this subject.) This report includes data on the Ohio River, Modified Ohio River, and Panama Canal type linkages. The study contains necessary data for conversion to prototype torque for all three of the different types of linkages. For direct connected type machines, prototype tests were made at Claiborne Locks and results of the tests are included herein for the determination of gate torque for any proposed direct connected lock machine of similar proportions. A curve of gate torque plotted against percentage of gate closure has been included so that torque at any other submergence or time of operation can be computed by application of Froude's law, adjusting the submergence and time to suit the new conditions.

(b) Temporal loads. In addition to the above-normal loads, the miter gate machinery should be designed to withstand the forces produced by a 1.25-ft (exceeding 30-sec duration) surge load acting on the submerged portion of the miter gate. For this case, the machinery must be designed to maintain control over the miter gate when the gate is in the miter position. In the recess position, control of the gate may be accomplished by automatically latching the gate in the recess. Normal machinery operating loads govern the machinery design for the intermediate positions.

(2) Operating time. A time of operation should be selected and should be based on the size of gate. For smaller gates (84-ft lock) an average time of 90 sec should be used and for the larger gates (110-ft locks) an average time of 120 sec would be suitable.

(3) Submergence. The design of the gate operating machinery should be based on the submergence of the

upper or lower gate, whichever is greater. The design should be the same for all four gate machines since there would be no savings in designing and building two different size machines. The increased design cost would offset the reduced cost of the material used in constructing the smaller machine.

(a) The submergence of the gate is the difference in elevation of the tailwater on the gate and the elevation of the bottom of the lower seal protruding below the gate. A submergence selected for design of the gate machinery should be the tailwater on the gate that would not be exceeded more than 15 to 20 percent of the time.

(b) The operating cylinder size should be selected to provide a force to operate the gate under these conditions utilizing approximately 900 to 3,000 psi effective pressure where a central pumping system is used. If higher than 1,000 psi is selected for the operating pressure, then measures to eliminate hydraulic shock should be considered because of the long hydraulic lines. Where local pumping units are used, an operating pressure of 1,500 to 3,000 psi will be satisfactory.

(c) The time of gate operation will automatically be lengthened when the required gate torque exceeds the available gate torque. This condition may occur during starting peaks or periods of higher submergence. This condition causes the pressure in the hydraulic cylinder to rise above the relief valve setting, which in turn reduces oil flow to the cylinder slowing down the gate and reducing the required pintle torque. This increases the total time of operation; however, this slower operation will be experienced for only 15 to 20 percent of the lock total yearly operating time.

(d) Peak torque can be reduced by nonsynchronous operation of the gate leaves. A considerable reduction in peak torque can be obtained by having one leaf lead the other by approximately 12.5 percent of the operating time. The time of opening would be increased by the amount of time one gate leads the other. It has been found that in actual practice very few gates are operated in this manner.

(4) Under gate clearance. Model tests revealed an increase in gate torque values as the bottom clearance decreased, regardless of the length of operating time. When using model similarity to compute gate loads, an adjustment should be made in accordance with model experience. Normally 2.5-ft to 3.5-ft clearance under the gate should be satisfactory.

(5) Machine components. General design criteria applicable to the various machine components are presented in paragraph 1-9. Allowable stresses may be increased one-third for temporal loading conditions.

c. Load analysis.

(1) Normal loads. Normal operating hydraulic loads on miter gates are primarily caused by submergence, speed of gate, and clearance under gate.

(a) Technical Report 2-651 (USAEWES 1964) indicates that the maximum torque recorded as the gate leaves entered the mitered position (closing) varied as the 1.5 power of the submergence; and the maximum torque recorded as the gate leaves left the mitered position (opening) varied as the 2.1 power of the submergence for the Ohio Linkage.

(b) For the Modified Ohio linkage, Technical Report 2-651 indicates that the maximum torque recorded as the gate leaves entered the mitered position (closing) varied as the 1.9 power of the submergence; and the maximum torque recorded as the gate leaves left the mitered position (opening) varied as the 2.2 power of the submergence.

(c) For the Panama-Type linkage, Technical Report 2-651 indicates that the maximum torque recorded as the gate leaves entered the mitered position (closing) varied as the 1.5 power of the submergence; and the maximum torque recorded as the leaves left the mitered position (opening) varied as the 1.7 power of the submergence.

(d) The report indicates that the maximum torque recorded decreased as the 1.0 power of the operating time for both the closing and opening cycles when using the Ohio Linkage.

(e) For the Modified Ohio linkage, the report indicates that the maximum torque recorded decreased, as the 1.1 power of the operating time for the closing cycle and as the 1.5 power for the opening cycle.

(f) The report indicates for the Panama-Type linkage that the torque decreased as the 1.1 power of the operating time for the closing cycle and as the 1.3 power for the opening cycle.

(g) Tests reveal that an increase in gate torque occurs when the clearance under the gate leaf is

decreased regardless of the length of operating time. Data from these tests are presented in Figure 2-10 and indicate the percentage increase in model torque for various bottom clearances relative to the torque observed with a 3-in. bottom clearance. These data can be used to adjust the observed torque values determined for a model bottom clearance of 3 in. when gate length is 3 ft.

(h) Nonsynchronous operation of miter gates results in slightly lower forces on the leading leaf. Forces on the lagging gate leaf are greater during most of the closing cycle and less during the opening cycle than similar forces recorded for synchronous operation of the gate leaves. The greatest reduction in torque appears to be when one gate is leading the other by approximately 12.5 percent of the total operating time.

(i) Barges in the lock chambers are found to have negligible effect on gate operating forces.

(j) The chamber length affects the gate torque in that the longer the chamber, the less the torque. As the length of time is increased, the less the chamber length affects the gate torque. Insufficient data are available to set up any definite adjustment factors for correcting for chamber length.

(k) Torque caused by gate pintle friction is of small magnitude and should not be considered in load calculations.

(l) When computing operating torque for a direct connected type miter gate drive, the curves shown in Plate B-87, Sheets 5 and 7, may be used. The curves are results of prototype tests made on Claiborne Lock and show gate torque plotted against percentage "closed." The torque from these curves may be adjusted to suit new conditions by the application of Froude's law as described in detail in paragraph 2-5d below. Since the curves were based on the use of a three-speed pump to slow the gate travel at beginning and end of cycle, it will be necessary to make similar assumptions on the proposed lock. Assuming a fast delivery rate of the pump at 1.0, the medium delivery rate should be 0.8 and the slow rate adjusted to 0.3 of the fast rate. A normal cycle would be to operate 10 percent of the gate angular travel at 0.3 capacity, 10 percent at 0.8 capacity, 60 percent at 1.0 capacity, 10 percent at 0.8 capacity, and 10 percent at 0.3 capacity. A comparison study made between this type of operation and the Panama-type linkage indicates that the direct connected machine, if operated as stated above, will compare favorably with the Panama machine in angular gate velocity (degrees per second) at all

positions. If one assumes that the angular velocities compare with the Panama-type machine, the maximum torque will vary as the 1.5 power of the submergence (closing) and 1.7 power of the submergence (opening). The operating time should vary as the 1.1 power for closing and the 1.3 power for the opening cycle.

(2) Temporal loads. Temporal hydraulic loads or surges are temporary changes in water level resulting in a differential water level on opposite sides of a lock gate. These surges or differential heads may be caused by overtravel of water in the valve culvert during filling or emptying, wind waves, ship waves, propeller wash, etc. Depending on the circumstances, this differential has been observed to vary from 1 to 2 ft. These forces do not affect the machinery power requirements, but they do affect the design of the gate machine components when the gate is at the recess or mitered position. These forces have been known to fracture gate struts and shear sector pins. See paragraph 2-5b(1)(b) for the description of these loads.

d. Determination of machinery loads.

(1) Normal loads. Normal miter gate operating machinery loads are difficult to determine and should, whenever possible, be determined from model or prototype tests. Data compiled by the Special Engineering Division of the Panama Canal Zone taken from tests made on the existing locks and a model for the third locks and model studies included in Technical Report 2-651 (USAEWES 1964) appear to be the most reliable sources for obtaining miter gate machinery loads available at this time. When using data from the model tests, it will be necessary to adjust the data on the basis of the scalar ratio between the model and the proposed lock. The length of the gate leaf is normally used for determining the scalar ratio. From the scalar ratio, Froude's law comparing prototype to model would be as follows:

$$\text{Scalar ratio} = \frac{\text{length of prototype leaf}}{\text{length of model leaf}} = L_R \qquad (2\text{-}9)$$

Volume, weight, and force $= (L_R)^3{:}1$

Time and velocity $= L_R{:}1$

Torque $= (L_R)^4{:}1$

When using machines having the Ohio linkage, the Modified Ohio linkage, or the Panama-type linkage, the forces on any size miter gate may be obtained from
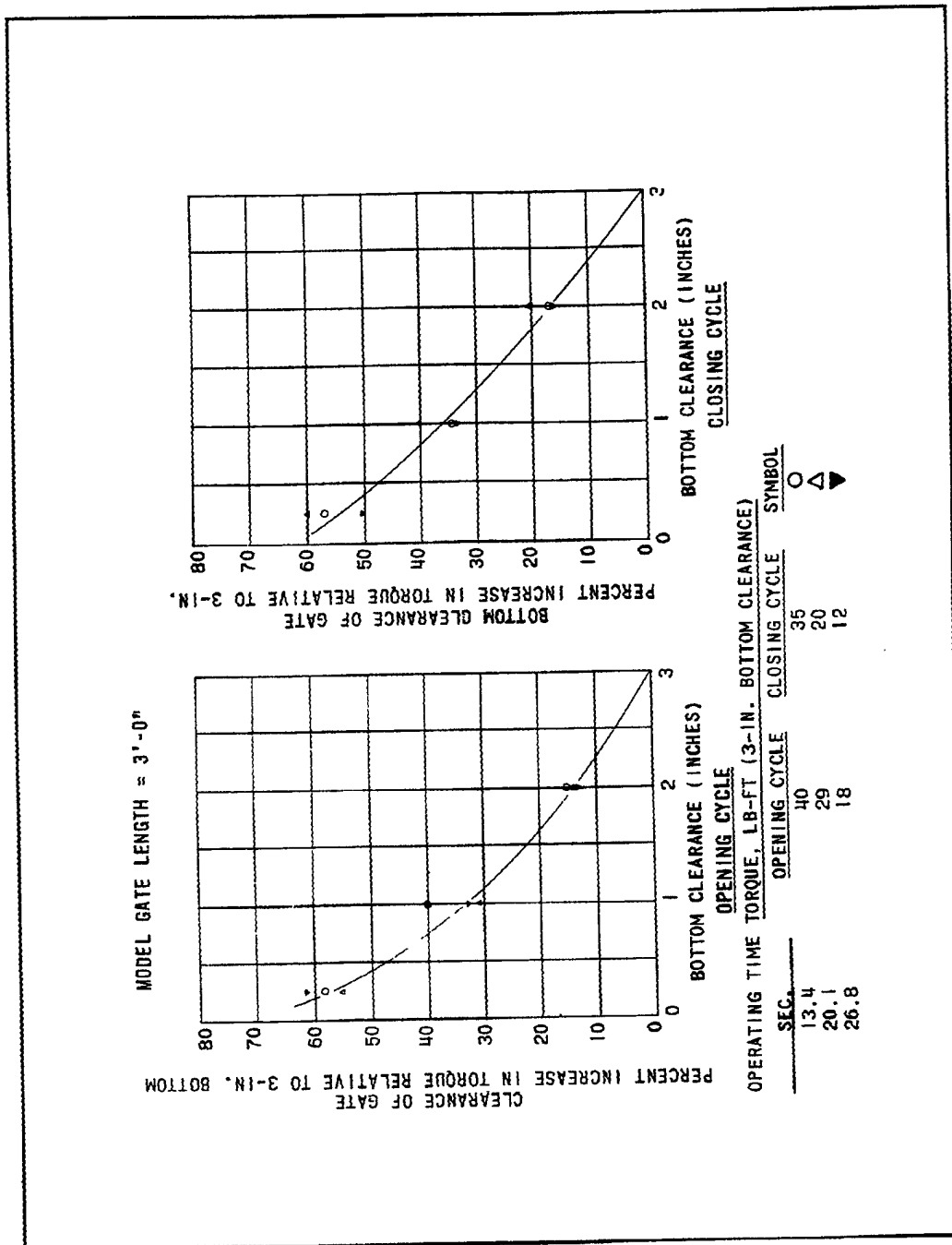
Figure 2-10. Relative effect of gate bottom clearance on torque, 4.0-ft submergence

curves shown in Plates B-83 through B-86 which are plotted from the results of the WES and Panama Canal Model Tests. Readings from the curves must be factored according to Froude's law for submergence, time of operation, and clearance under gate. Curves are based on lock lengths of 600 ft or greater. Forces for shorter lengths would be slightly greater; however very few, if any, locks would be built with chamber lengths less than 600 ft.

(a) Computation of pintle torque for Panama Canal and Ohio-type linkage. If the proposed lock gate is in the same scalar ratio with respect to length of gate and the submergence and time of operation as shown on curves and the type of linkage are the same, the pintle torque would equal the pintle torque at each position indicated on the curves multiplied by the ratio of gate leaf lengths to the 4th power.

$$P_1 = P(L_1/L)^4 \tag{2-10}$$

where

P_1 = pintle torque of proposed lock gate at selected position

P = pintle torque shown on curve of model study at selected position

L_1 = leaf length, pintle to miter end, proposed lock gates

L = leaf length, pintle to miter end for curves that have been plotted on model study

In the event the ratios of gate lengths L_1/L, submergence S_1/S, and the square of the time of operation T_1/T are not of the same scalar ratio, the formula should be expanded as follows:

$$P_1 = P(L_1/L)^4(S_1/2)^x(T_2/T_1)^y \tag{2-11}$$

where

P_1, P, L_1, and L = same as in Equation 2-10

S_1 = submergence of proposed lock gate

S = actual submergence of model gate upon which curves are based

S_2 = adjusted submergence of model lock gate
   = $S(L_1/L)$

T_1 = time of operation of proposed lock gate (See arc of travel adjustment below.)

T = actual time of operation of model gate upon which curves are based

T_2 = adjusted time of operation of model lock gate = $T\sqrt{L_1}\,/L$

x = power to which submergence must be raised, for particular type linkage

y = power to which time must be raised, for particular type linkage

NOTE: If only one ratio for either submergence or the square of the operating time is not of the same ratio as gate leaf length L_1/L, then only the ratio not in agreement with L_1/L need be considered in the equation.

If the arcs of gate travel differ from that shown on model curves, it will be necessary to adjust the operating time of the proposed lock T_1 to use in Equation 2-11 as follows:

Let T_A = adjusted operating time

or

$$T_A = T_1 \frac{(\text{ arc of travel, proposed lock })}{(\text{arc of travel, on model curves})} \tag{2-12}$$

$$= T_1(K_1/K)$$

T_A must be substituted in equation for T_1

Use of Equations 2-10 through 2-12 results in a pintle torque which makes no allowance for motor slip since all of the model curves were based on uniform speed of hydraulic cylinder or constant rpm of the motor. If a portion of the required gate torque curve overloads the motor, the resulting time of gate operation would be slower, which in turn would result in lower gate torque during this period. The same would occur when operating the gates with a hydraulic cylinder. Overloading the cylinder would result in some of the oil being bypassed

through relief valves which in turn would slow down the gate during the overload period. When using the Ohio-type linkages and torque data from Technical Report 2-651, the pintle torque P_t should be adjusted for undergate clearance in addition to submergence and time. The percentage increase can be obtained from curves in Figure 2-10. Where a proposed lock is not subjected to flooding, electric motor operation with Panama-type or Modified-Ohio-type linkage may be considered. A high-torque, high-slip motor should be used and should be selected so that the normal full load torque available would not be exceeded by the required torque of the machine more than 15 to 20 percent of the time. Peak torque during the overload period should not exceed 150 percent of full load torque. This can be determined by plotting the required torque based on curves computed from model tests described above and by plotting available motor torque curves at various degrees of slip and superimposing these curves over the required curves. Typical calculations for determining loads using the Ohio-type linkage (hydraulic operation) are shown in Plate B-79. Calculations for determining loads using the Panama-Canal-type linkage (electric motor operation) for the same design conditions are shown in Plate B-80.

(b) Computation of pintle torque for direct connected linkages. The kinematics of this type of machine should be developed so as to provide the shortest practicable piston stroke. This will require the gate pin connection to be located out from the pintle a distance of 20 to 25 percent of the gate length, and the center line of the cylinder gimbal bracket to be located so as to give the best effective operating arm about the pintle at each position throughout the entire stroke of the piston. With use of this linkage and a uniform traveling piston, gate angular velocity will be greatest at the extreme closed or open position of the gate. Uniform travel of the piston is therefore undesirable, and it will be necessary to slow down the speed of the piston near the closed and open positions by use of a variable volume pump in the oil circuit. By slowing the travel near open or closed position of the gate, angular travel rates will be comparable with the Panama Canal linkage. Figure 2-11 shows comparison curves for angular velocity of gate plotted against percent "closed" for Panama Canal Third Locks linkage and for Claiborne Lock direct connected linkage with and without variable speed control. Time of operation should be selected for the proposed lock that will give angular gate velocities approximately equal to the velocities shown on the curve for Panama Canal. Gate pintle torque should then be taken from the prototype curves shown in Plate B-87, Sheets 3 and 5, and adjusted by means of Froude's Law of Similarity to the

submergence and time requirements of the proposed lock using the same exponents as used for the Panama Canal linkage. Load computations for a direct connected machine are shown in Plate B-87, Sheets 1-10.

(2) Temporal loads. The resulting machinery loads for the case of temporal loading are based on a 1.25-ft differential head superimposed on the normal gate submergence. These loads are considered applicable only when the gate is at either the miter or recess position. In operation, these forces are resisted by a hydraulic load brake rather than by pumped oil pressure at the miter position. This is done by automatically engaging a high pressure hydraulic relief valve at the position of travel where these loads occur. For this load condition, a 33.33 percent overstress is allowed for component design. In the recess position, this load is resisted by automatically latching the gate. Only the sample computations for the Ohio-River-type machine shown in Plate B-79, Sheets 1-12, include the temporal load computations.

e. Operating machinery control.

(1) Hydraulically operated machines. A complete description of the two basic types of hydraulic systems for locks along with pertinent hydraulic system design criteria are presented in paragraph 1-11j. Control of these systems has utilized manual, solenoid controlled, pilot operated, and cartridge valves.

(a) With manual control, a small control stand is located over a recess on one lock wall near the gate machinery and is equipped with control valve operating levers. A schematic piping diagram of a manually controlled "central pumping" system is shown in Plate B-61. This diagram includes the connections for the tainter valves and shows the complete lock operating hydraulic system.

(b) Recent control systems utilize solenoid-controlled pilot-operated four-way and solenoid-controlled cartridge valves to control the flow of oil to cylinders. This makes the system more flexible and enables the inclusion of an electrical interlock between the miter gates and lock fill and empty valves so that the lock chamber water level cannot be changed before all gates are closed. Changing the water level in the lock chamber before the gates are closed creates a swell head on the partially closed gates which could cause them to slam shut damaging the gate and/or gate machinery. This type of control is recommended rather than the manual control. A schematic
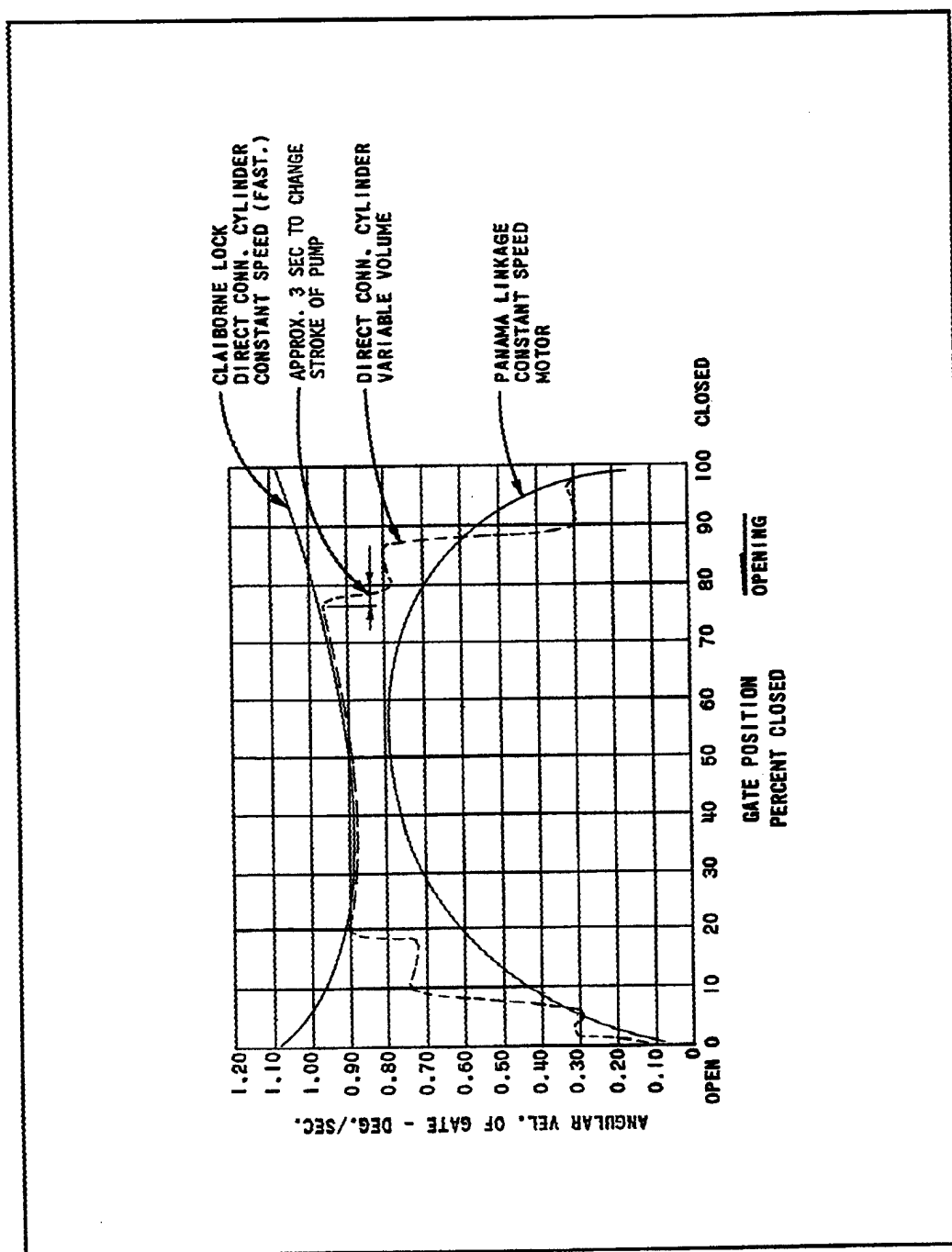
Figure 2-11. Gate velocity comparison curves

piping diagram of this control system is shown in Plate B-62. (See also Plate B-63.)

(c) The majority of locks using electrically operated directional control valves have two points of lock control (one located near each gate in a control booth). Some recently designed locks have utilized a single point of control located in the control building. Each control point consists of a control console with all the control features associated with a normal lockage. These features include valve control, bubbler system, lock lighting, navigational signal, maintain pressure, and alarms. At some projects with dual control points, the control consoles may become inundated during high water and, therefore, should be designed so that they are located above the anticipated high water (by elevating the control booths) or so that they can easily be removed. A control console layout is shown in Plate B-69.

(d) Locks with single points of control have their gate and valve control console located in the control building near the upstream gate. So that the operators can view the downstream gate during opening and mitering, a multicamera closed circuit television system is also provided. A simplified control stand is provided near the downstream gate for the operation of the gate if the television system becomes inoperative or during periods of maintenance. Means for disconnecting or transferring control from this control stand when not in use should be provided.

(e) Whether single or dual control points are utilized, the control features are the same. This system provides two speeds for miter gates and two speeds for culvert valves. This scheme also provides a high degree of automation and protection against misoperation. Electrical interlocks are used in the control circuit to produce the desired operating sequence. Limit switches located at the miter point of the gates, in the gate machinery recesses and the culvert valve recesses, are used to prevent the upstream culvert valve from being opened when the downstream gate and/or valves are open and vice versa. These interlocks are also used to prevent slamming of the gates or changing the lock chamber water level when gates are mismitered. One miter limit switch is located near the top of the gate and two miter limit switches are located near the bottom of the gate. (See miter gate limit switch locations shown in Plate B-67.) Since the gate's bottom seal resistance will prevent the lower portion of the gate from closing properly even though the top is mitered, only the top miter limit switch and the rack-mounted gate-mitered limit switches must be actuated before the corresponding filling or emptying

sequence can be started. If, after the valves are opened and at least one of the lower gate mounted miter switches is not actuated, the valve being opened will automatically close. A logic diagram for this system is shown in Figure 2-12. A manual backup system should be provided for gate and valve control should the automatic control system fail. The manual control system is independent of the automatic control system and bypasses all gate-valve interlocks.

(f) The electrical controls systems utilize either electro-mechanical relays or solid state controllers. The electro-mechanical relay system for the valve/gate interlock system is shown in Plate B-66, Sheets 1-5. The same type of diagram can be used if solid state controllers are to be used. Miscellaneous power and control diagrams are shown in Plate B-65.

(g) In case of a control system failure that could shut down the lock, a backup system should be provided. One backup system used on several locks is indicated in Plate B-70. The manual backup panel is connected to a receptacle located under each console. When connected and a transfer switch is placed in the "backup" position, the operator has direct electrical control of the solenoid-operated directional control valve. When in use, the panel bypasses all automatic control and electrical interlock features.

(2) Electrically operated machines. At projects where floodwaters will not overtop the lock wall or machinery recesses, a modified Ohio machine with electric motor drive may be economical and desirable. At these projects, control equipment consists of the combination of full voltage magnetic controllers, limit switches, and control switches arranged to produce the desired operating sequence. The limit switches used in previous designs were of the traveling-nut type in NEMA four enclosures with heaters. Due to the unavailability of travel nut limits switches, cam-operated switches are being used. Control consoles similar to that described above for the hydraulic system are usually used. Electrical valve-gate interlock features should be similar to that described above for the hydraulic system. Strut stress limit switches are used to cut off the motor if the strut stresses in either tension or compression beyond a preset point. This will protect the strut and machinery if an obstruction is encountered. A typical electrical schematic of a control system using a single-speed motor is shown in Plate B-71. Control for a two-speed motor is shown in Plate B-72.
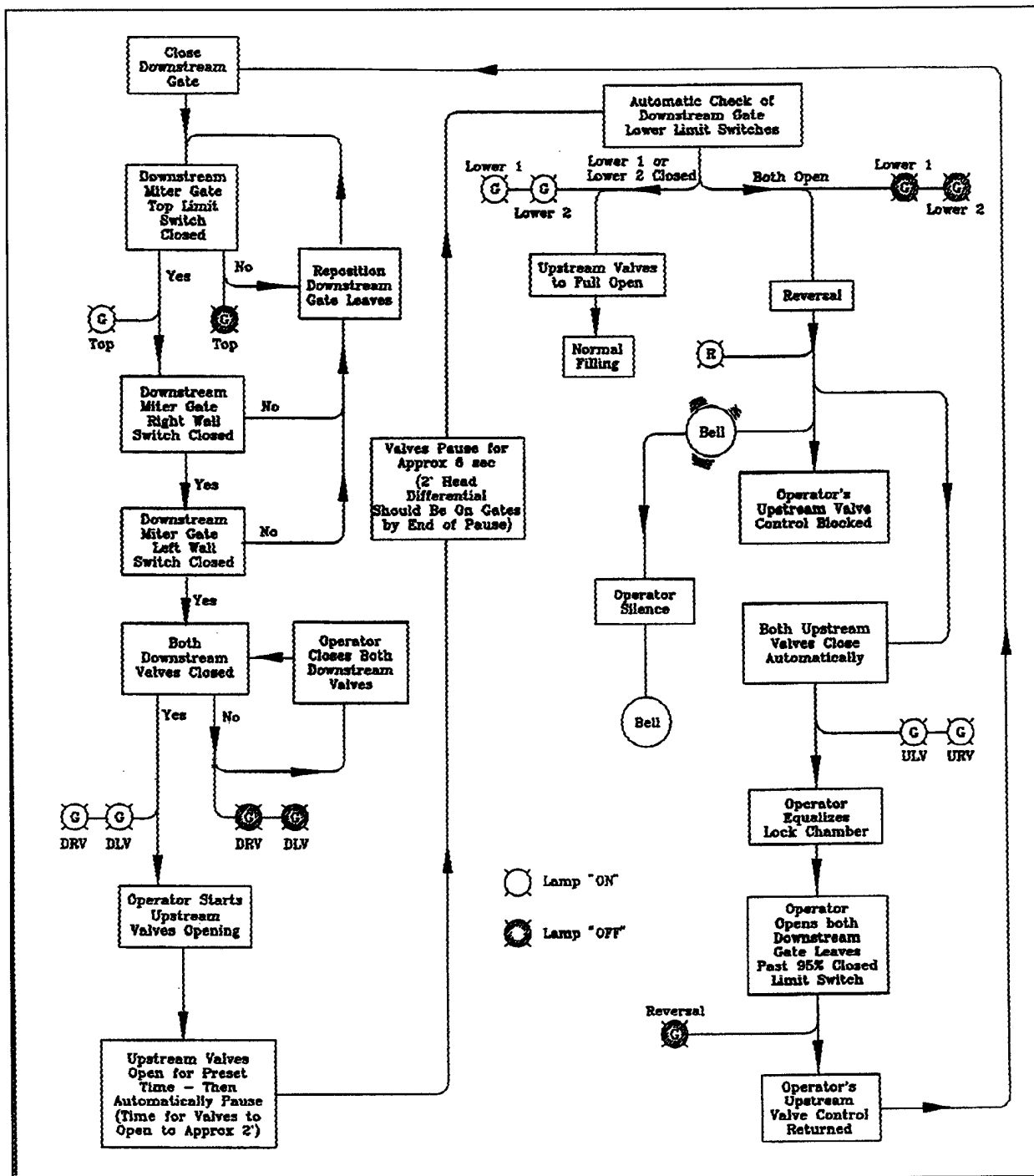
Figure 2-12. Lock filling sequence. (Lock emptying sequence is similar.)

f. Miscellaneous equipment and systems.

(1) Machinery stops. In order to deal with ordinary construction tolerances, a means must be provided to adjust the miter gate machinery linkage at installation. It has usually been found satisfactory to provide approximately 2 in. of overtravel at each end of the hydraulic cylinder and rack to allow for adjustment. With the linkage connected and the miter and recess positions established for the gate, stops are installed and adjusted to limit the machinery motion to these extreme positions. One stop is placed so as to stop the rack when the gate is mitered; another is placed to stop the sector arm when the gate is recessed. Details of this arrangement are shown in Plate B-49.

(2) Automatic greasing. A system should be provided to automatically grease each miter gate pintle bushing and gudgeon pin as shown in Figure 2-13. The system should dispense a measured amount of grease to each location automatically during gate movement. An automatic grease system is available with a built-in programmable controller, which will allow variations in grease cycles and quantity of grease provided. Since the grease systems have to be field-tuned, for a particular lock application, the programmable controller should be a desirable option. The pintle bushing should be designed to permit the installation of an O-ring seal and a grease return line which can be monitored to ensure grease delivery to the pintle bushing. The system should include automatic monitoring equipment to warn of a malfunction. Special consideration should be given to the layout and sizing of the grease lines to ensure proper operation and minimum pressure loss. Grease lines should be stainless steel pipe of adequate wall thickness for the anticipated pressures. Grease lines should be located in areas of the gate that afford the greatest degree of protection from damage due to ice and drift. The pumping unit should be located near the gate to minimize grease line length. Provisions should be made to remove the pumping unit if flooding is likely. For more details, see Plate B-13, Detail A.

(3) Automatic gate latches. Latches should be provided for holding the gates in the recess. The latches should be designed to automatically latch the gate when it comes into the recess. Release of the latches should be accomplished automatically each time a "gate close" function is initiated. A recess latch is shown in Plate B-68. The system should be provided with latched and unlatched position indication.

(4) Maintain pressure system.

(a) A maintain pressure system should be provided to hold miter gates closed with hydraulic pressure. The present system (as indicated in Plate B-66) is designed to hold the gate leaves together against wind loading or small water surges prior to changing the chamber water level. Upstream gate maintain pressure is used during lock pit emptying, and downstream gate maintain pressure is used during lock pit filling operation. This maintain pressure system is activated by the lock operator depressing a pushbutton on operator console. This system can be deactivated manually by the operator or is automatically deactivated when the gate under maintain pressure is opened or after the valves are opened for a predetermined time to allow an adequate head of water on the gates to keep them mitered. The maintain pressure system should utilize the valve "slow" or the lowest pumping rate available.

(b) The tandem center hydraulic system is not preferred but, if used, or if retrofitting a tandem center system, the maintain pressure system will provide pressure to the miter gate cylinder in the gate closed position through the use of a standard bladder-type accumulator. This accumulator, located in each miter gate machinery recess, will be charged and pressure maintained through a pilot-operated check valve installed in series with each miter gate cylinder. A pressure switch, sensing accumulator pressure, will ensure adequate pressure through a time delay circuit. An indicator lamp on the control console will be illuminated when pressure in the maintain pressure system is adequate. At the same time the gate four-way valve will be automatically shifted from "close" to "neutral" position.

(5) Fire protection system. In addition to the requirements of EM 1110-2-2608, a fire-protection system may be provided for miter gates. In operation, this system provides a dense spray of water on the miter gate surface between the gate and barges which may be on fire in the lock chamber. This spray would keep the gates cool and minimize distortion in the event of a fire. The system consists of a series of water spray nozzles located along the top of each miter gate leaf discharging into the lock chamber. These spray nozzles are fed by high capacity raw water pumps. One pump is provided for each lock chamber. Control stations are located near each gate with controls for starting and stopping the raw water pump and also for opening and closing the motorized valve in the supply line to each set of gate nozzles.
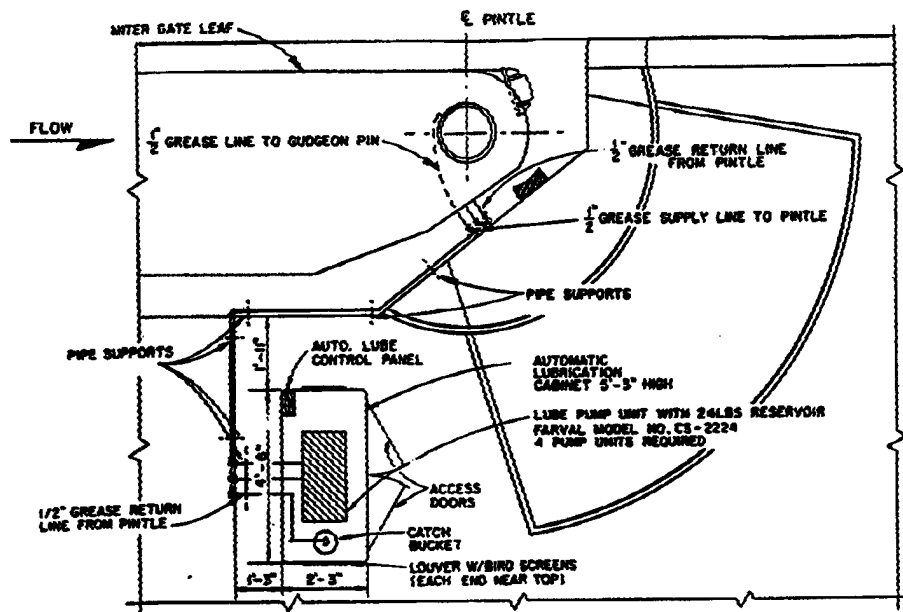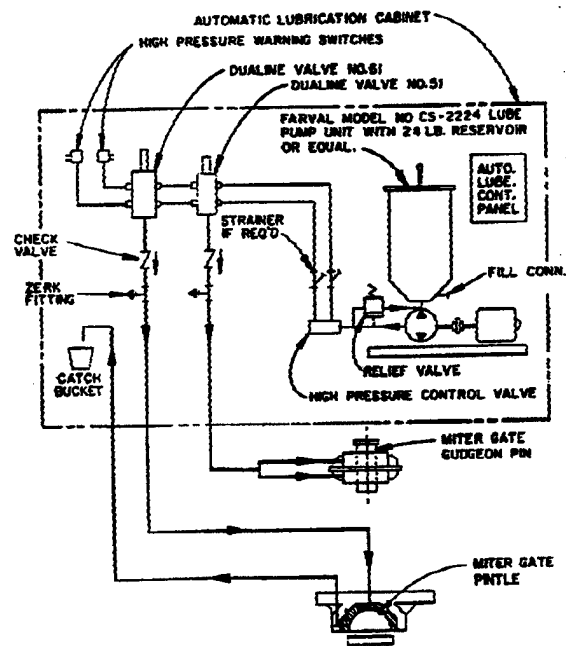
Figure 2-13. Automatic lubrication system schematic

The decision to include the gate spray system should be evaluated on a case-by-case basis depending upon the consequences of the loss of the gate.

(6) Overfill and overempty control system. The overfill and overempty system should be evaluated on a case-by-case basis and should be considered mainly on high lift locks or locks with long narrow approaches. A control system has been developed to eliminate overfilling and overemptying of the lock chamber. This system measures water levels by sensing the back pressure of compressed air constantly bubbling through tubes extending below the surface of the water. This system compares the level of water in the lock chamber with that of the upper pool when filling and the lower pool when emptying and at a predetermined time begins closing the fill or empty valves, respectively. This action dissipates the energy of flowing water in the culverts, thereby eliminating lock overfill or overempty. The operators at locks which utilize the gate-mounted limit switches have developed an operating technique which eliminates or greatly reduces overfill or overempty. As the lock fills or empties, the operator watches the indicating lights controlled by the gate-mounted limit switches. When the lights start going off the operator opens the appropriate gate.

Chapter 3
Diagonal Design, Miter Gates

3-1. Diagonal Design

The following information is applicable to open frame gates and is essentially the same as that presented in "Torsional Deflection of Miter-Type Lock Gates and Design of the Diagonals" (USAED, Chicago, 1960) with only minor modifications.

3-2. Definitions of Terms and Symbols

Deviations from these symbols are noted at the places of exception.

Δ - Total torsional deflection of the leaf measured, at the miter end, by the movement of the top girder relative to the bottom girder. (See Figure 3-1.) The deflection is positive if the top of the miter end is moved upstream relative to the bottom.

Positive diagonal: A diagonal which decreased in length with a positive deflection of the leaf. (See Figure 3-4.)

a - The cross-sectional area of that part of a horizontal girder which lies outside the midpoint between the skin and the flange. (See Figure 3-6.)

A - Cross-sectional area of diagonal.

A' - Stiffness of the leaf in deforming the diagonal. Until more test data are available, it is suggested that A′ be taken as the sum of the average cross-sectional areas of the two vertical and two horizontal girders which bound a panel times:

$1/8$ for welded horizontally framed leaves with skin of flat plates,

$1/20$ for riveted vertically framed leaves with skin of buckle plate. (See paragraph 3-4i(1).)

b - Distance from the center line of the skin plate to the flange of a horizontal girder. (See Figure 3-6.)

c - The smaller dimension of a rectangular cross section.

d - Pitch diameter of the threaded portion of the diagonals.

D - Prestress deflection for a diagonal. D is the deflection of the leaf required to reduce the stress in a diagonal to zero. D is always positive for positive diagonals and negative for negative diagonals.

E - Bending modulus of elasticity.

E_s - Shearing modulus of elasticity.

h - Height of panel enclosing diagonal.

H - Vertical height over which H is measured, usually distance between top and bottom girders.

I - Moment of inertia about the vertical axis of any horizontal girder.

I_x - Moment of inertia, about the horizontal centroidal axis, of a vertical section through a leaf. (See Figure 3-5.)

J - Modified polar moment of inertia of the horizontal and vertical members of the leaf.

K - A constant, taken equal to 4. (See paragraph 3-4i(2).)

l - The larger dimension of a rectangular cross section.

L - Length of a diagonal, center to center of pins.

M - Torque required to turn the sleeve nut to prestress diagonal. (Refer to Equation 3-28.)

n - Number of threads per inch in sleeve nut of diagonal.

N - Number of turns of nut to prestress diagonal. (Refer to Equation 3-27.)

Q_o - Elasticity constant of a leaf without diagonals. (See paragraph 3-4i(2).)

Q - Elasticity constant of diagonal defined by Equation 3-18.

R_o - Ratio of change in length of diagonal to deflection of leaf when diagonal offers no resistance. (Refer to Equation 3-11.) R_o is positive for positive diagonals and negative for negative diagonals.

R - Ratio of actual change in length of diagonal to deflection of leaf. (Refer to Equation 3-13.) R is positive for positive diagonals and negative for negative diagonals.

s - Unit stress in diagonal.

S - Total force in diagonal.

t - Distance from center line of skin plate to center line of diagonal. (For curved skin plate, see paragraph 3-4h.)

T_z - Torque area. Product of the torque T of an applied load and the distance z to the load from the pintle. z is measured horizontally along the leaf. T_z is positive if the load produces a positive deflection.

v - Distance from center line of pintle to extreme miter end of leaf.

w - Width of panel. (Refer to Figure 3-1.)

X - Distance from center line of skin plate to vertical shear center axis of leaf. (Refer to Equation 3-30.)

y - Distance to any horizontal girder from the horizontal centroidal axis of a vertical section through a leaf.

y_n - Distance to any horizontal girder from the horizontal shear center axis of a vertical section through a leaf.

Y - Distance to horizontal shear center axis from the horizontal centroidal axis of a vertical section through a leaf. (Refer to Equation 3-29.)

3-3. Introduction

A lock-gate leaf is a very deep cantilever girder with a relatively short span. The skin plate is the web of this girder. If the ordinary equations for the deflection of a cantilever under shearing and bending stresses are applied, the vertical deflection of the average leaf will be found to be only a few hundredths of an inch. Because the skin plate imparts such a great vertical stiffness to the leaf, the stresses in the diagonals are a function of only the torsional (twisting) forces acting upon the leaf. These forces produce a considerable torsional deflection when the gate is being opened or closed. It is this torsional deflection and the accompanying stresses in the diagonals with which this chapter is concerned.

  a. The shape of the twisted leaf is determined geometrically. Then the work done by the loads is equated to the internal work of the structure. From this, the resistance which each diagonal offers to twisting of the leaf is computed as a function of the torsional deflection of the leaf and the dimensions of the structure. Equations for torsional deflection of the leaf and stresses in the diagonals are derived.
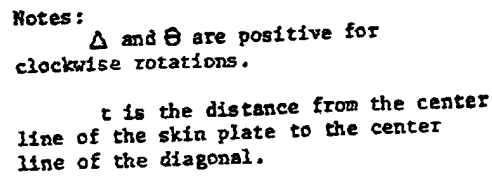
  b. Experiments were made on a model of the proposed gates for the MacArthur Lock at Sault Ste. Marie. Tests were also conducted in the field on the lower gates of the auxiliary lock at Louisville, KY. Both experiments indicate that the behavior of a gate leaf is accurately described by the torsional deflection theory.

  c. Examples of the application of the theory are presented together with alternate methods for prestressing the diagonals of a leaf.

3-4. Geometry

In order to make a torsional analysis of a lock gate, the geometry of the deflected structure must be known. The change in length of the diagonal members will be determined as a function of the torsional deflection of the leaf. For the present, the restraint offered by the diagonals will not be considered.

  a. Diagonal deformation. In Figures 3-2 and 3-3, the panel ak of Figure 3-1 is considered separately. As the leaf twists the panel ak twists as indicated by the dotted lines. In Figure 3-3, movements of all points are computed relative to the three reference axes gf, gb, and gk shown in Figure 3-2. The girders and skin plate are free to twist, but they remain rectangles, except for second-order displacements. Therefore, the three reference axes are always mutually perpendicular. Let δ_o equal the change in length of either diagonal of Figure 3-3.

Notes:
 Δ and Θ are positive for clockwise rotations.

 t is the distance from the center line of the skin plate to the center line of the diagonal.

Plane of skin plate

Figure 3-1. Schematic drawing of a typical miter-type lock-gate leaf

$$\delta_o = \frac{d}{w} t \cos \alpha + \left(\frac{d}{h} t \sin \alpha \right)$$

$$= \frac{dt}{w} \frac{w}{(w^2 + h^2)^{1/2}} + \frac{dt}{h} \frac{h}{(w^2 + h^2)^{1/2}} \qquad (3\text{-}1)$$

$$= \frac{2dt}{(w^2 + h^2)^{1/2}}$$

b. Sign convention. For the necessary sign convention, let the deflection d be positive when the top of the leaf moves upstream in relation to the bottom. With a positive deflection, those diagonals that decrease in length are considered positive diagonals. With negative deflection, where the top of the gate moves downstream in relation to the bottom, those diagonals that decrease in length are considered negative diagonals.
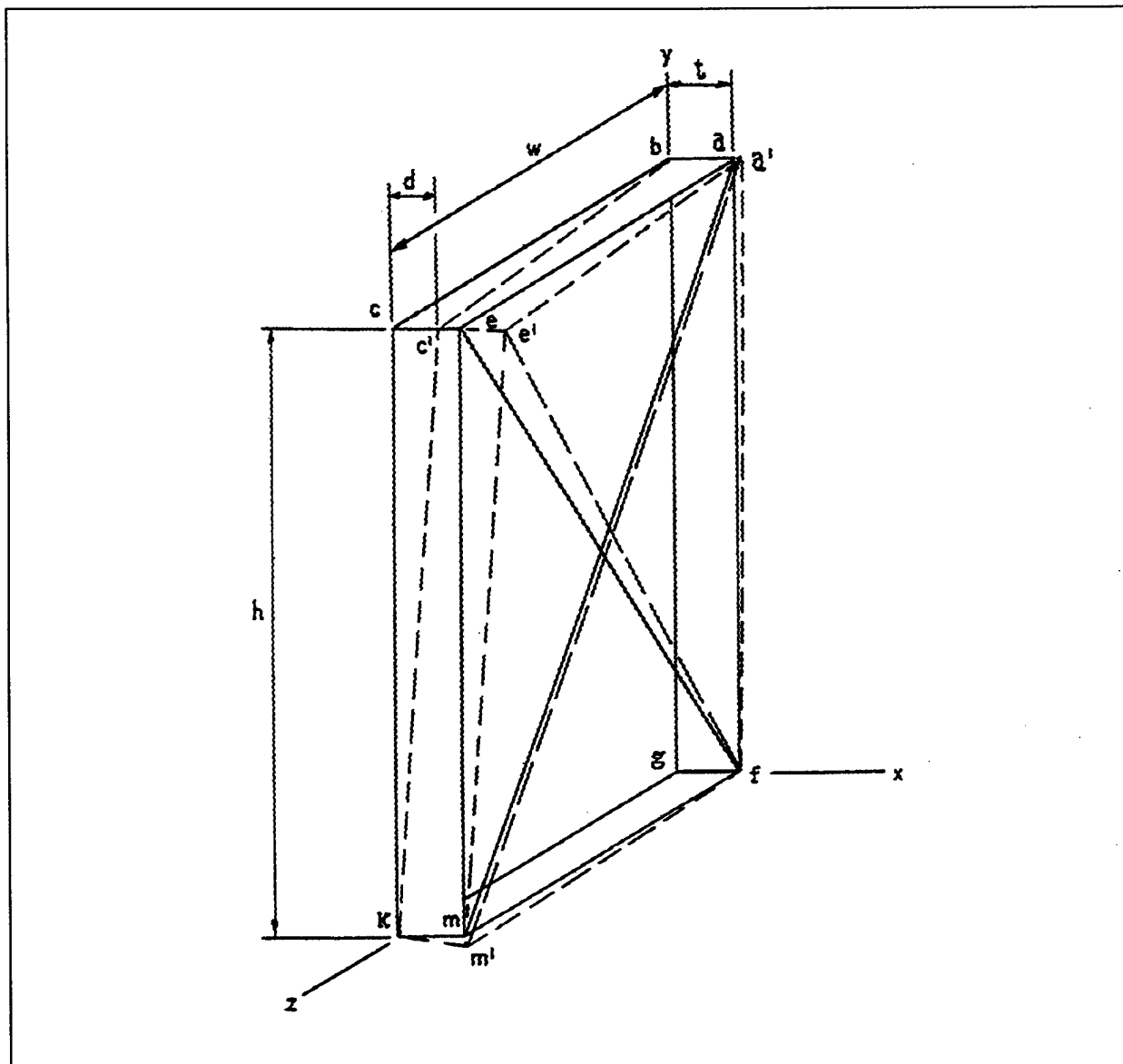
Figure 3-2. Schematic drawing of panel ak

c. Ratio of diagonal deformation to panel deflection. In the following information a decrease in any diagonal length, either positive or negative diagonal, is designated as a positive change in length. Let r_o be defined as follows:

$$r_o = \frac{\delta_o}{d} \qquad (3\text{-}2)$$

which from Equation 3-1 becomes

$$r_o = \pm \frac{2t}{(w^2 + h^2)^{1/2}} \qquad (3\text{-}3)$$

r_o is positive for positive diagonals and negative for negative diagonals. Figure 3-4 illustrates the positive and negative diagonals of a typical leaf.
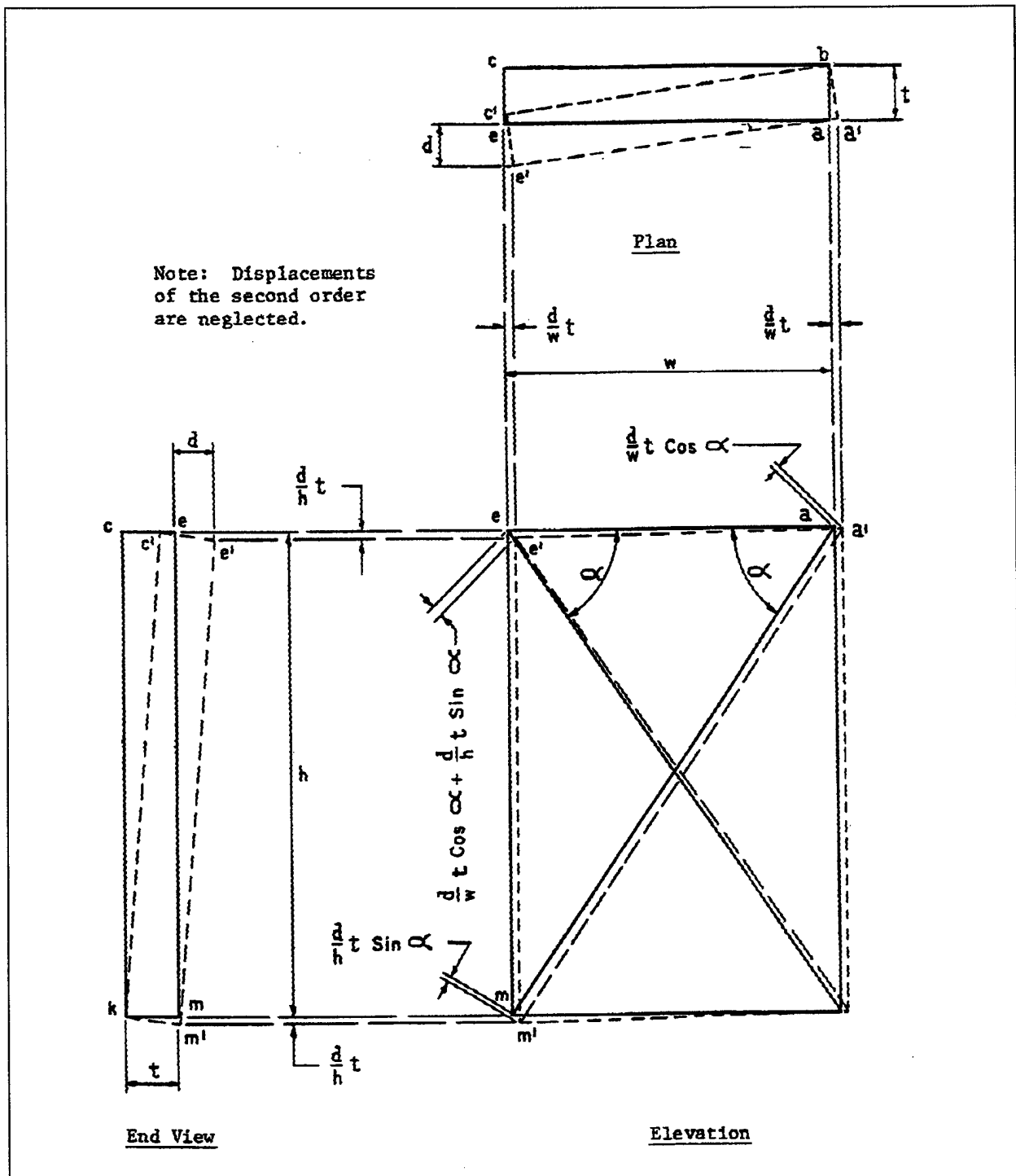
Note: Displacements
of the second order
are neglected.

Plan

$$\frac{d}{w}t$$

$$\frac{d}{w}t$$

w

$$\frac{d}{w}t \text{ Cos } \alpha$$

$$\frac{d}{h}t$$

$$\frac{d}{w}t \text{ Cos } \alpha + \frac{d}{h}t \text{ Sin } \alpha$$

$$\frac{d}{h}t \text{ Sin } \alpha$$

h

$$\frac{d}{h}t$$

t

End View

Elevation

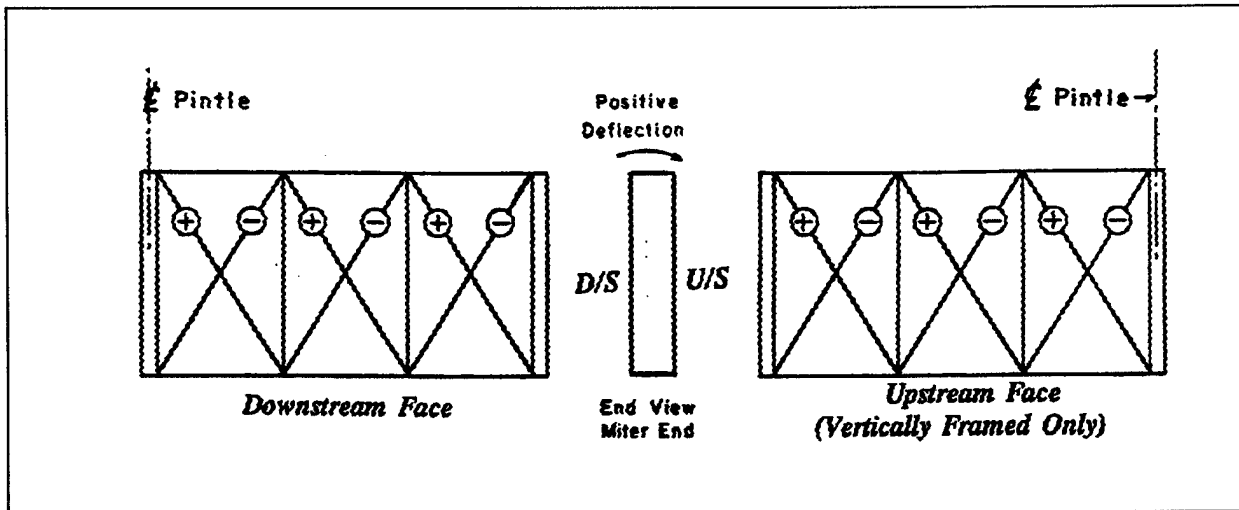**Figure 3-3. Displacements of points of panel ak**

Figure 3-4. Positive and negative diagonals of a typical leaf

d. Diagonal restraint. Up to this point, the restraint offered by the diagonal members has not been considered. Equation 3-1 gives the change in length of a diagonal if the diagonal offers no resistance. However, unless a diagonal is slack, it does offer resistance to change in length. Therefore, when a deflection d is imposed upon the panel, the length of the diagonal does not change an amount δ_o. The actual deformation is δ which is less than δ_o by some amount δ'.

$$\delta = \delta_o - \delta' \qquad (3\text{-}4)$$

(1) It is evident that δ is inversely proportional to the resistance of the diagonal and that δ' is inversely proportional to the ability of the panel to elongate the diagonal. Let the resistance of the diagonal be measured by its cross-sectional area A. Then

$$\frac{\delta}{\delta_1} = \frac{A'}{A} \qquad (3\text{-}5)$$

in which A' is a measure of the stiffness of the panel in deforming the diagonal. The significance of A' and the method of determining its magnitude will be discussed later. Let it be assumed for the present, however, that A' is known.

(2) Solving Equation 3-4 for δ' and substituting its value in Equation 3-5,

$$\frac{\delta}{\delta_o - \delta} = \frac{A'}{A} \qquad (3\text{-}6)$$

(3) Let r be defined as the ratio of the actual deformation of the diagonal to the deflection of the panel.

$$r = \frac{\delta}{d} \qquad (3\text{-}7)$$

(4) Using Equations 3-2 and 3-7, Equation 3-6 can be written

$$\frac{rd}{r_o d - rd} = \frac{A'}{A}$$

and solving for r

$$r = \frac{A'}{A + A'} r_o \qquad (3\text{-}8)$$

It will be noted that when the diagonal offers no restraint (that is to say that $A = o$), $r = r_o$.

(5) Let Δ be defined as the torsional deflection of the whole leaf; see Figure 3-1. It is evident that the relative deflection d from one end of a panel to the other is proportional to the width of the panel

$$d = \frac{w \Delta}{v} \tag{3-9}$$

(6) Let R_o be defined as follows:

$$R_o = \frac{\delta_o}{\Delta} \tag{3-10}$$

Substituting the values of δ_o and Δ from Equations 3-2 and 3-9, respectively

$$R_o = \frac{r_o d}{(v/w)d} = \frac{wr_o}{v}$$

which, from Equation 3-3, becomes

$$R_o = \pm \left(\frac{2wt}{v(w^2 + h^2)^{1/2}} \right) \tag{3-11}$$

Let R be defined by

$$R = \frac{\delta}{\Delta} \tag{3-12}$$

Substituting in Equation 3-12 the values of δ and Δ obtained from Equations 3-7 and 3-9, respectively

$$R = \frac{rd}{(v/w)d} = \frac{w}{v} r$$

which, from Equation 3-8 becomes

$$R = \frac{w}{v} r_o \frac{A'}{A + A'} = R_o \frac{A'}{A + A'} \tag{3-13}$$

e. Deflection of leaf and stresses in diagonals. In general, the diagonals of any lock-gate leaf will have, as a result of adjustments, an initial tension which is here called a prestress. The prestress in all diagonals is not the same. However, for any diagonal the leaf can be deflected by some amount Δ, such that the stress in that diagonal is reduced to zero. The magnitude of this deflection is a measure of the initial tension in the diagonal and will be called the prestress deflection D for that diagonal. By selecting the value of D, the designer can establish a definite prestress in any diagonal (see examples 1 and 2 in this chapter). It can be seen from the definition of a positive diagonal that D is positive for positive diagonals and negative for negative diagonals.

(1) Referring to Equation 3-12, it is seen that the prestress in any diagonal results from a change in length equal to R $(-D)$. If an additional deflection Δ is imposed upon the leaf, the total change in length will be

$$\delta = R \ (-D) + R \ (\Delta) = R \ (\Delta - D) \tag{3-14}$$

and similarly

$$\delta_o = R_o(\Delta - D) \tag{3-14a}$$

Since a positive value of δ represents a decrease in length, the elongation of a diagonal is $(-\delta)$ and the total force is

$$S = \frac{(-\delta) \ EA}{L}$$

which from Equation 3-14 becomes

$$S = \frac{-REA}{L} (\Delta - D) \tag{3-15}$$

(2) If the diagonal offered no resistance to change in length, its deformation would be, from Equation 3-4, δ_o

$= \delta + \delta'$. The force in the diagonal, therefore, not only elongates the diagonal an amount δ'. The total work done by the force S in the diagonal is, therefore

$$W_D = \frac{1}{2}(\delta + \delta') = \frac{1}{2}S\delta_o$$

which, by adapting Equation 3-14a, becomes

$$W_D = \frac{1}{2}SR_o(\Delta - D) \qquad (3\text{-}15a)$$

Substituting the value of S from Equation 3-15

$$W_D = \frac{-RR_oEA}{2L}(\Delta - D)^2 \qquad (3\text{-}16)$$

(3) The force S in the diagonal is produced by some external torque T. The work done is

$$W_T = \frac{1}{2}T\theta$$

It is evident from Figure 3-1 that the angle of rotation θ of any section of the leaf is proportional to the distance z from the pintle. If the leaf is twisted an amount $(\Delta\text{-}D)$, the angle of rotation at the end is $(\Delta\text{-}D)/h$. Therefore, at any section

$$\theta = \frac{(\Delta - D)}{h}\frac{z}{v}$$

Making this substitution for θ in the equation for W_T

$$W_T = \frac{(\Delta - D)}{2hv}T_z \qquad (3\text{-}17)$$

The term T_z is the area of the torque diagram for the torque T. T_z will hereinafter be called "torque-area." (See definitions.)

(4) Equating the sum of W_D and W_T as given by Equations 3-16 and 3-17, respectively, to zero and simplifying

$$T_z - \frac{RR_oEAhv}{L}(\Delta - D) = 0$$

Let

$$Q = \frac{RR_oEAhv}{L} \qquad (3\text{-}18)$$

Then

$$T_z + Q(D - \Delta) = 0 \qquad (3\text{-}19)$$

Since T_z is the torque-area of the external load, the quantity $Q(D\text{-}\Delta)$ may be called the resisting torque-area of the diagonal. All factors of Q are constant for any diagonal. Q, therefore, is an elasticity constant of the diagonal. Even if there were no diagonals on a leaf, the structure would have some resistance to twisting. Let the resisting torque-area of the leaf without diagonals be defined as $Q_o(\Delta)$. A prestress deflection D is not included in this definition since the leaf does not exert any torsional resistance when it is plumb. In other words, D for the leaf is zero. Q_o will be evaluated later. For the present, let it be assumed that Q_o is known.

(5) The total torque-area of all external loads plus the torque-area of all resisting members must equal zero. Therefore, Equation 3-19 may be written as follows:

$$\Sigma(T_z) - Q_o\Delta + \Sigma[Q(D - \Delta)] = 0 \qquad (3\text{-}20)$$

in which $\Sigma[Q(D\text{-}\Delta)]$ includes all diagonals of the leaf.

(6) Since Δ is a constant for any condition of loading, Equation 3-20 may be solved for Δ.

$$\Delta = \frac{\Sigma(T_z) + \Sigma(QD)}{Q_0 + \Sigma Q} \qquad (3\text{-}21)$$

which is the fundamental equation for deflection.

(7) If the leaf is to hang plumb ($\Delta = 0$) under dead load, the numerator of the right-hand member of Equation 3-21 must equal zero.

$$\Sigma(T_z)_{D.L.} + \Sigma(QD) = 0 \tag{3-22}$$

Equation 3-22 represents the necessary and sufficient condition that a leaf hang plumb under dead load.

(8) If the live-load and dead-load torque-areas are separated, Equation 3-21 may be written

$$\Delta = \frac{\Sigma (T_z)_{L.L.} + \Sigma (T_z)_{D.L.} + \Sigma (QD)}{Q_o + \Sigma Q}$$

But if Equation 3-22 is satisfied, $\Sigma(T_z)_{D.L.} + \Sigma(QD) = 0$

Therefore

$$\Delta = \frac{\Sigma (T_z)_{L.L.}}{Q_o + \Sigma Q} \tag{3-23}$$

which is the fundamental equation for deflection of a leaf with all diagonals prestressed. Equation 3-23 shows that the live load deflection of a leaf is independent of the prestress deflection D for any diagonal.

(9) The unit stress in a diagonal is obtained by dividing Equation 3-15 by A,

$$s = \frac{RE}{L} (D - \Delta) \tag{3-24}$$

which is the fundamental equation for unit stress in a diagonal.

(10) If the maximum allowable unit stress is substituted for s in Equation 3-24, the maximum allowable numerical value of $(D-\Delta)$ will be obtained. Since the maximum values of Δ are known from Equation 3-23, the maximum numerical value of D for any diagonal can be determined.

(11) The diagonals of a gate leaf should be prestressed so that all of them are always in tension (see paragraph 3-4*j*). If this is to be so, the quantity $(D-\Delta)$ must always represent an elongation of the diagonal. Therefore, for positive diagonals, D must be positive and

greater than the maximum positive value of Δ. For negative diagonals, D must be negative and numerically greater than the maximum negative deflection. These then are the minimum numerical values of D.

(12) Values of D shall be selected such that they satisfy Equation 3-22 and lie within the limits specified above. If this is done, the leaf will hang plumb under dead load, and none of the diagonals will ever become overstressed or slack. In addition, the deflection of the leaf will be held to a minimum since a prestressed tension diagonal is in effect a compression diagonal as well.

f. Preliminary area of diagonals. In the design of diagonals, it is desirable to have a direct means of determining their approximate required areas. With these areas, the deflection and stresses can then be found and, if considered unacceptable, the areas could be revised and the process repeated. A close approximation to the required area can be found by equating Equations 3-15a and 3-17.

$$\frac{1}{2} SR_o (\Delta - D) = -\frac{(\Delta - D)}{2hv} T_z$$

Treating R_o as equal for all diagonals, substituting sA for S, and taking Σ for all diagonals in a set,

$$A = -\frac{\Sigma T_z}{R_o hv} \tag{3-25}$$

With the above, the maximum positive ΣT_z will give the total area required in the set of negative diagonals and the maximum negative ΣT_z, the area for the positive diagonals.

g. Vertical paneling of leaf. By differentiating Q with respect to h, it has been found that the most effective slope for a diagonal exists with $h = w(2)^{1/2}$. If h approaches 2.5 w, it will be desirable to subdivide the panel vertically to reduce the area of the diagonals or, possibly, to reduce their total cost. The example in paragraph 3-6*i* shows the slight modification necessary to apply this method of design to panels subdivided vertically. In general, diagonals are most effective in panels having the ratio of

$$\frac{\text{Greater dimension}}{\text{Lesser dimension}} \approx (2)^{1/2}$$

h. Curved skin plate. The geometric relationships derived herein apply equally well to a leaf with curved or stepped skin plating and the more general value of *t* is the plan view divided by the width. The plan-view area is the area bounded by the skin plate, the center line of the diagonals, and the side boundaries of the panel.

i. Discussion.

(1) The constant A': Except for the constants A' and Q_o, all properties of the gate leaf are known, and the deflection of the leaf and the stresses in the diagonals can be determined. A' appears in the equations for both R and Q as follows:

$$R = \frac{A'}{A + A'} R_o \qquad (3\text{-}13)$$

$$Q = \frac{RR_o EAhv}{L} + \frac{R_o 2EAhv}{L} \times \frac{A'}{A + A'} \qquad (3\text{-}18)$$

(a) Measurements were made on the 1/32-size celluloid model of the gates for the MacArthur Lock at Sault Ste. Marie (Soo). Field measurements were also made on the lower gate at Louisville, KY, and 29 gate leaves in the Rock Island District on the Mississippi River. The Soo and Louisville gates are horizontally framed and have flat skin plates and the Mississippi gates are vertically framed and have buckle skin plates. In all cases, δ was determined from strain gage readings on the diagonal and Δ was measured directly as the leaf was twisted. Equation 3-12 gave the value of R. A' was then calculated from Equation 3-12 in which the theoretical value of R_o obtained from Equation 3-11 was substituted.[1] Values of A' obtained are:

Sault Ste.
Marie A' = 0.025 in.^{2} (model)
            = 0.025 x (32)^2 = 26 in.^{2} (prototype)

Louisville   = 13 in.^{2}

Mississippi
River Gates = 10 in.^{2}

(b) It seems reasonable to suppose that the size of the horizontal and vertical girders to which the diagonal

is attached can be used as a measure of A'. At Sault Ste. Marie, A' is 0.14 of the sum of the cross-sectional areas of the girders which bound the diagonal. At Louisville the factor is 0.07 and for the Mississippi River gates, 0.045. Additional experiments are desirable. However, until more data are obtained, it is believed that a conservative value of A' for the average diagonal is the sum of the average cross-sectional areas of the girders which bound the diagonals times 1/8 for the heavier, welded, horizontally framed leaves with flat skin plate and 1/20 for the lighter, riveted, vertically framed leaves with buckle plates.

(c) It is believed that for any gate leaf diagonal, A' will usually be as large or larger than A. Therefore, a large error in A' will result in a much smaller error in the fraction $A'/(A + A')$. Hence, it is necessary to know the approximate value of A' in order to apply the foregoing theory. This is especially true of the diagonal stress, as can be seen from Equation 3-24 where an error in A' produces an error R which is opposite to that produced in $(D - \Delta)$. Thus, stress is nearly independent of A'.

(2) The constant Q_o: Q_o is an elasticity constant which is a measure of the torsional stiffness of a leaf without diagonals. Q_o is a function of many properties of the leaf. However, it seems reasonable that the torsional work done upon the typical main members of the leaf, as the leaf twists, might be used as a measure of Q_o.

(a) When a leaf twists, the horizontal and vertical members rotate through angles of Δ/h and Δ/v, respectively. The work done in any member is

$$W = \frac{1}{2} \frac{E_s J}{v} \frac{(\Delta)^2}{h^2} \text{, for horizontal members}$$

$$W = \frac{1}{2} \frac{E_s J}{h} \frac{(\Delta)^2}{v^2} \text{, for vertical members}$$

E_s = shearing modulus of elasticity

J = modified polar moment of inertia

The work done by an external torque is, from Equation 3-17

$$W_T = \frac{\Delta}{2hv} T_z$$

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[1] In the model test, the experimental value of R_o was also determined and was found to agree with the theoretical value within 1 percent.

In this case the value of D in Equation 3-17 is zero since the members are not supplying a resisting torque when the deflection is zero. Equating W_T to W and solving T_z,

$$T_z = \frac{E_s J}{h} \Delta \text{, for horizontal members}$$

$$T_z = \frac{E_s J}{v} \Delta \text{, for vertical members}$$

The quantities $E_s J/h$ and $E_s J/v$ might be called the values of Q_o for

horizontal and vertical members, respectively, hence,

$$Q_o = K E_s \Sigma (J/h + J/V) \tag{3-26}$$

where the value of K as determined experimentally for the Sault Ste. Marie model and the Louisville prototype is approximately 4. Until additional measurements can be made, this value should be used.

(b) Nearly all members of a leaf subject to torsion are made up of narrow rectangles. For these, the value of J is

$$\frac{\Sigma l (3)^3}{3}$$

Where plates are riveted or welded together, with their surfaces in contact, they are considered to act as a unit with c equal to their combined thickness.

(c) Using Equation 3-26, Q_o can be evaluated very easily, as will be demonstrated in the examples. However, in many cases Q_o can be neglected entirely without being overly conservative. In neglecting Q_o, the stiffness of the leaf itself, without diagonals, is neglected. An experiment has shown this stiffness to be small. Furthermore, anyone who has seen structural steel shapes handled knows how easily they twist. Unless closed sections are formed, the total stiffness of a leaf is just the arithmetic sum of the stiffness of all members taken individually and this sum can be shown to be small. The lack of torsional stiffness is also illustrated by a known case in which a leaf erected without diagonals twisted several feet out of plumb under its own dead weight. Q_o is included in examples 1 and 2 but its values are only 5 percent and 3 percent, respectively, of the total stiffnesses, Q, contributed by the diagonals.

(3) Load torque-areas. By definition, a load applied through the shear center of a section will cause no twisting of the section. In computing dead load torque-area the moment arm of the dead load is, therefore, the distance from the vertical plane through the shear center to the center of gravity of the leaf. The method of locating the shear center of a lock-gate leaf is given in paragraph 3-4k. The water offers resistance against the submerged portion of the leaf as it is swung. There is also an inertial resistance to stopping and starting. Since the resultant of these resistances is located near or below the center height of leaf and the operating force is near the top of the leaf, a live load torsion results. From tests performed to determine operating machinery design loads, the maximum value of the above-mentioned resistances was found to be equivalent to a resistance of 30 psf on the submerged portion of the leaf. Until additional data become available, it is recommended that this value be generally used in computing the live load torque-area. However, in the case of locks accommodating deep-draft vessels, water surges are created during lockages that appear to exceed the above-mentioned equivalent load. Until more data are obtained, it is recommended that for these cases, 45 psf or higher be used.[2] The diagonals will also be checked for obstruction loads and temporal hydraulic loads and the governing loading condition will be used for diagonal design. For definition of obstruction and temporal hydraulic loads, refer to paragraphs 2-1b and 3-8, respectively.

(4) Skin plate consisting of buckle plates. The theory is based upon the assumption that the skin plate remains rectangular at all times. If the skin consists entirely of buckle plates and if the shear in the skin is large, this assumption may be in error. However, if the diagonals extending downward toward the miter end are made larger or prestressed higher than the others, the prestress in them can be made to carry a large part, if not all, of the dead load shear. Although the action of buckle plates in shear is not understood, it is recommended that they be treated as flat plates. As a precaution, however, the diagonals should be prestressed to carry as much of the dead load as possible within the restrictions imposed upon D (see paragraph 3-4e). The reader is referred to example 2, paragraph 3-6.

j. Methods for prestressing diagonals. It is essential that all diagonals be prestressed. With all diagonals

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[2] The operating strut mechanism should also then be designed for these larger forces.

prestressed, none will ever alternately bow out and then snap back into position during operation of the leaf. It is certain that this buckling was responsible for some of the failures of diagonals which occurred in the past. Prestressing also reduces the torsional deflection of the leaf to a minimum, since all diagonals are always acting. There are two general methods of prestressing diagonals. In one method, the leaf is twisted a precomputed amount and the slack in the diagonals is removed. In the other, the sleeve nut on the diagonal is turned a precomputed amount. Caution should be taken when using the twist of the leaf method where the leaf has top and bottom torque tubes. Due to the increased leaf stiffness, there is the need for a higher jack capacity (150+ tons), and a possibility that damage could be caused to the leaf or other gate components. The high jacking loads could cause damage such as localized buckling of plates, excessive deflection in the quoin post, damage to the grease seals, pintle, and pintle socket, etc. These two methods are discussed below:

(1) Twist-of-the-leaf-method. The quoin end of the leaf is made plumb and the miter end is anchored to prevent horizontal movement in either direction. This is done by either tying the miter end to the sill or tying the top miter end to the lock wall and using a hydraulic jack at the bottom. Then with a power-operated cable attached to the top of the miter end, the leaf is twisted the computed D for one set of diagonals and the slack is removed from this set. During this operation, the other set of diagonals must be maintained slack. The leaf is then twisted in the opposite direction the computed D for the other set of diagonals, and the slack is removed from them. (See example 2, paragraph 3-6.) It is important that all the slack be removed without introducing any significant tension in the diagonal. This can best be accomplished by lubricating the nut and manually turning it with a short wrench. Since the turning resistance increases abruptly with the removal of the slack, the point of removal can be felt. As a further precaution, a strain gage is recommended on the diagonal being tightened. The maintained deflection of the leaf should also be watched, since more than a slight tension in the diagonal will cause a change in deflection of the leaf. On existing gates in which the diagonals were not designed by this method, it may be necessary to overstress some diagonals during the prestress operation. A stress of $0.67F_y$ for this one-time load is considered permissible where F_y is the yield strength of the diagonal material. The prestressing force required (normal to the leaf, at the upper miter corner) is obtained from Equation 3-21 as

$$p = \frac{\Delta \, (Q_o = \Sigma Q) - \Sigma Q - (\Sigma T_z) \, D.L.}{hv}$$

where Q includes only the active diagonals. (See the example, paragraph 3-6i.)

(2) Turn-of-the-nut-method. In this method, it is essential that the nut be very well lubricated with a heavy lubricant. Initially, all diagonals must be slack and, during the prestressing operation, each diagonal must be maintained slack until it is reached in the prestressing sequence. Then the slack is removed from the first diagonal to be prestressed and the diagonal is clamped to the leaf, as close to both ends of the nut as possible, to prevent twisting of the diagonal during the nut-turning operation. The clamping should restrain twisting of the diagonal without preventing elongation of the full length. In removing the slack, the same precautions should be observed as in the previous method. The nut is then turned the precomputed N for the diagonal. This procedure is repeated for each succeeding diagonal. (See example 1, paragraph 3-5.) The large torque required to fully tighten the nut can be provided by a mechanically supplied force at the end of a long wrench. The nut must be turned to shorten the diagonal an amount $\delta_o = R_o \, (D-\Delta)$. Therefore, if n is the number of threads per inch, the number of turns required is

$$N = \frac{nR_o(D-\Delta)}{2} \tag{3-27}$$

in which Δ is the initial deflection measured in the field. From textbooks on machine design, the torque M required to turn the nut to obtain the desired prestress, sA, is

$$M = sA \tan (\theta + \alpha)d$$

where d is the pitch diameter of the threads, θ is the friction angle which from tests may be taken equal to $\tan^{-1}(0.15) = 8°30'$, and α is the helix angle which, within the size range that would be used on diagonals, may be taken as a constant angle of $1°30'$. Further the maximum unit stress s is given by Equation 3-24.

Therefore

$$M = 0.18 \, sAd = \frac{0.18 \, REAd(D-\Delta)}{L} \tag{3-28}$$

in which Δ is determined from Equation (3-21), with only the active diagonals included.

(3) Comparison of methods. The twist-of-the-leaf method has been used, with excellent results, considerably more than the turn-of-the-nut method. While the turn-of-the-nut method appears to have some merit, such as reduction in setup time, the elimination of overstressing any diagonal during prestressing, and the elimination of strain gages, this method is not recommended due to the difficulties encountered during prestressing. The diagonal bar tends to twist and it is extremely difficult to provide sufficient torque to the sleeve nut or turnbuckle without first deflecting the leaf. The turn-of-the-nut method is included for information but for normal installations the twist-of-the-leaf method should be used.

k. General method for locating shear center of a lock gate leaf. The shear center of a gate leaf is the point through which loads must be applied if the leaf is not to twist.

(1) Horizontal shear center axis. Consider the leaf restrained against rotation about the hinge. To prevent twisting of the leaf due to horizontal forces, the resultant of these forces must be located so that the load to each horizontal girder is proportional to their relative stiffnesses. This is equivalent to saying that the resultant must be located along the horizontal gravity axis of the girder stiffnesses. This gravity axis is then the horizontal shear center axis and is located a distance from the centroidal axis equal to

$$Y = \frac{\Sigma(I_n \, Y)}{\Sigma I_n} \tag{3-29}$$

in which I_n is the moment of inertia of any horizontal girder about its vertical centroidal axis.

(2) Vertical shear center axis. A lock-gate leaf is a cantilever beam supported by the pintle gudgeon. A vertical load on the leaf causes tension above and compression below the centroidal axis. Therefore, longitudinal shearing stresses exist in the structure and shearing stresses of equal magnitude and at right angles to the longitudinal shearing stresses exist in the plane of any vertical cross section.

(a) A shear diagram with arrows to indicate the direction of the shear is shown in Figure 3-5. Since the shears of the flanges of the top and bottom girders are small and since the shear on one side of a flange is usually equal and opposite to the shear on the other side of the same flange, these shears will be neglected. The horizontal shears in the webs of the top and bottom girders produce a torsional moment on the section which must be balanced by the torsional moment VX of the vertical forces if the leaf is not to twist.

(b) The shear diagram for the web of the right-hand part of the top girder is redrawn to a larger scale in Figure 3-6. The trapezoidal shape of this diagram is based upon the assumption that the thickness of the web is constant within the limits of the diagram. The ordinate of the diagram at any point is VQ/I. The area of the shear diagram is the total horizontal shear S on this part of the girder. This area is $(VQ/I)b$ in which VQ/I is the ordinate at the center of the diagram. Therefore, Q is the statical moment, about the centroidal axis of the whole section, of that part of the section lying within the circle of Figure 3-6. If a is the area of this part of the section, then $Q = ay$, and

$$S = \frac{Vay}{I} \, b$$

The torsional moment of all these horizontal shearing forces about the horizontal shear center axis is

$$T = \Sigma \, \frac{Vay}{I} \, by_n = \frac{V}{I} \, \Sigma(ayby_n)$$

If the leaf is not to twist, the sum of the moments of the vertical and horizontal forces must equal zero.

$$VX + \frac{V}{I} \, \Sigma(ayby_n) = 0$$

and solving

$$X = - \left[\frac{\Sigma(ayby_n)}{I} \right] \tag{3-30}$$

which is the horizontal distance from the center line of the skin to the shear center of the section. In this equation, a is always positive and b and X are positive when measured to the right of the skin and negative when measured to the left.
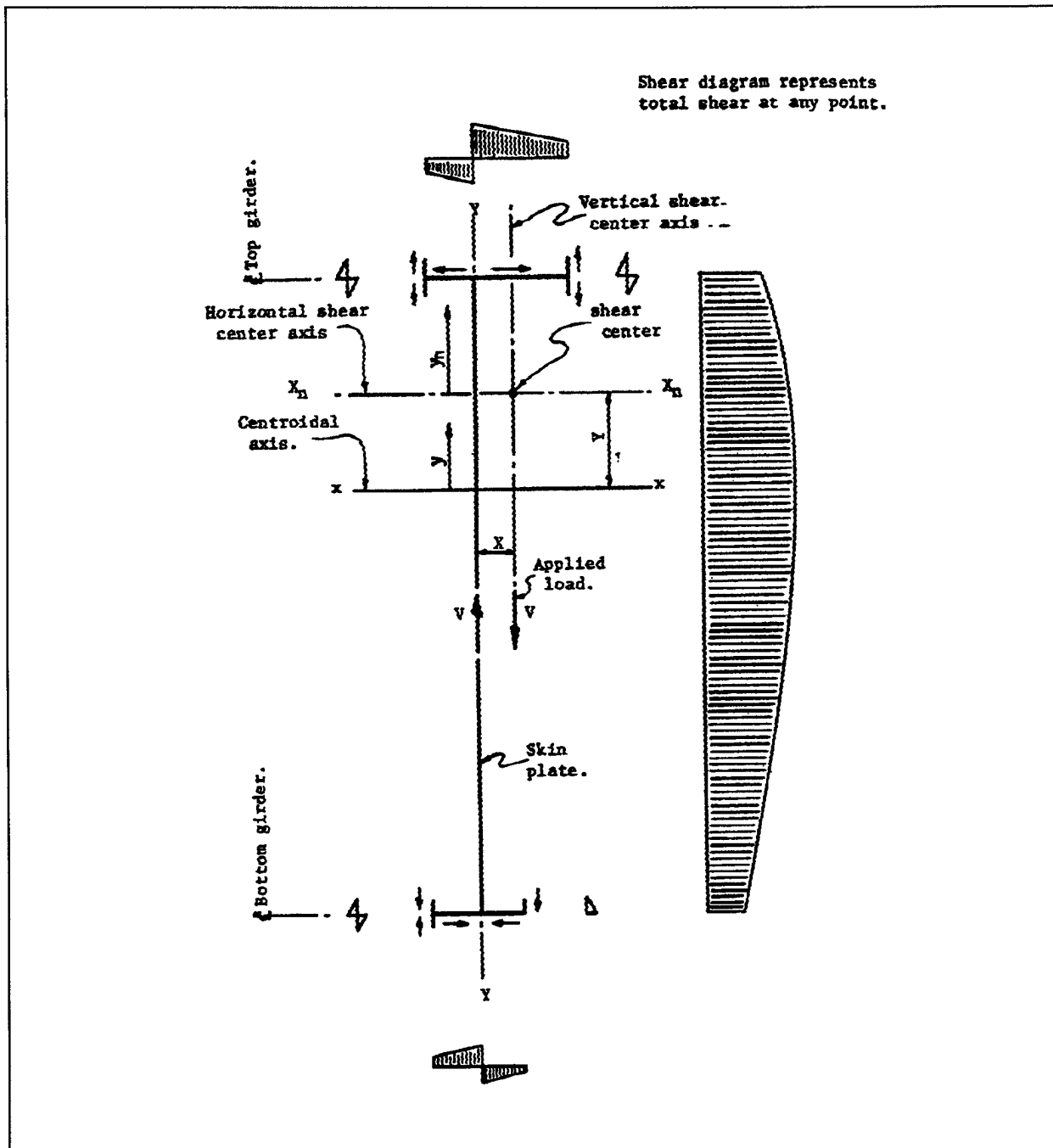
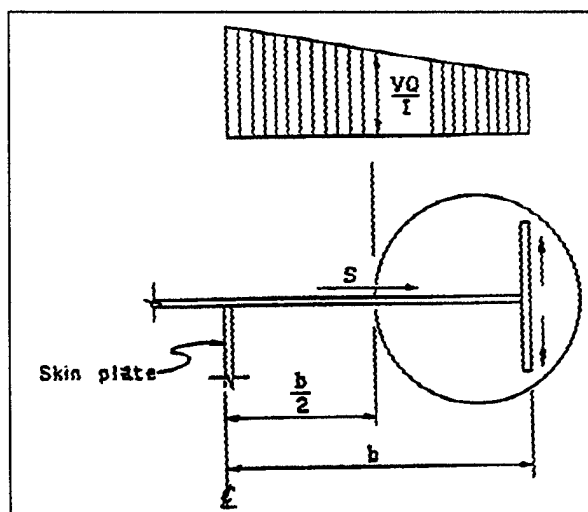Figure 3-5. Shear diagram for typical vertically framed lock-gate leaf

Figure 3-6. Shear diagram for web of the right-hand part of the top girder

c. Equations 3-29 and 3-30 are general expressions, independent of the number of horizontal girders, and as such apply equally well to horizontally framed gates.

3-5. Example 1, Horizontally Framed Gate

Lower operating gates, MacArthur Lock, Sault Ste. Marie (See Figure 3-7).

a. *Evaluation of A'.* The bottom and top girders and the vertical end girders are W36X150 with a cross-sectional area of 44.16 in^2. Therefore, A' is (see paragraph 3-4i(1))

$$A' = 1/8 \ (4 \times 44.16) = 22 \ in.^2$$

b. *Evaluation of Q_o.* (See paragraph 3-4i(2) and Table 3-1.)

$$Q_o = K \ E_s \ \Sigma(j/h + j/v)$$

$$Q_o = 4 \times 12 \times 10^6 \ \frac{4320.0}{3 \times 684.0}$$

$$+ \ \frac{590}{3 \times 529}$$

$$= 120.0 \times 10^6 in. \ lb.$$

(3-26)

c. *Location of shear center.* (See Figure 3-5.) Computations for the centroidal axis and moment of

inertia of the vertical section through the leaf (see Figure 3-7) are not given. Computations of distances x and y are given in Tables 3-2 and 3-3, respectively.

$$y = 310 \ in. \quad I = 42.6 \times 106 \ in.^4$$

Horizontal shear center axis:

$$Y = \frac{\Sigma(I_n \cdot y)}{\Sigma I_n}$$

$$= \frac{-1.61 \ x \ 10^6}{162,000}$$

(3-29)

$$= -10.0 \ in.$$

Vertical shear center axis:

The value of b for all girders is -36.1 in.

$$X = -\frac{b}{I}\Sigma(ayy_n)$$

$$= -\left(\frac{-36.1}{42.6 \times 10^6}\right) x \ 13.54 \times 10^6$$

(3-30)

$$= 11.4 \ in.$$

d. *Load torque areas.* (See paragraph 3-4i(3).) The forces which produce twisting of the leaf are shown in Figure 3-8. Computation of the torque area is given in Table 3-4. Computations for the location of the center of gravity and deadweight of the leaf are not given. Because this lock handles deep-draft vessels, a water resistance of 45 psf is used.

e. *Evaluation of R_o, R, and Q.*

$$R_o = \pm \frac{2wt}{v(w^2 + h^2)^{1/2}}$$

$$= \pm \frac{2 \times 483 \times 37.8}{529 \ (483^2 + 684^2)^{1/2}}$$

$$= \pm 0.0822$$

Required size of diagonals:
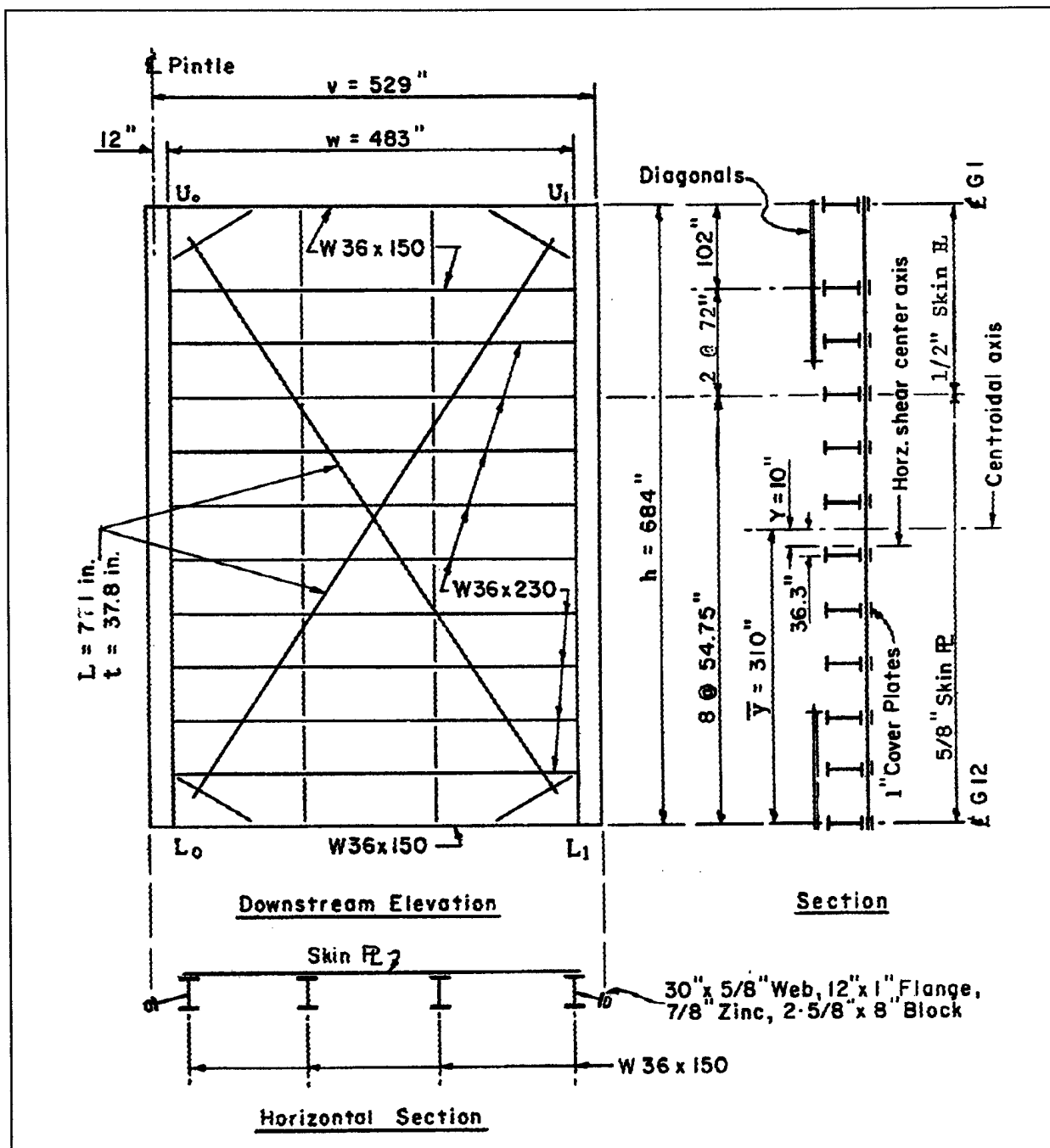
For diagonal U_oL_1,

Figure 3-7. Lower gate leaf, MacArthur Lock, Sault Ste. Marie

Table 3-1
Computation of Modified Polar Moment of Inertia J

Elements	n (No. of Elements)	1 (in.)	c (in.)	nlc^3 Horizontal Members	Vertical Members
Horizontal Girders					
US flange,	3	12.0	2.44	520.0	-
Web,	3	34.0	0.63	30.0	-
DS flange, (G1, 2, and 12)	3	12.0	0.94	30.0	-
US flange,	9	16.5	2.78	3190.0	-
Web,	9	33.5	0.77	140.0	-
DS flange, (G3 through G11)	9	16.5	1.26	300.0	-
Skin (between flanges)					
1/2" plate	1	203.0	0.50	30.0	-
5/8" plate	1	308.0	0.63	80.0	-
Vertical Girders					
US flange	4	12.0	1.57	-	190.0
Web	4	34.0	0.62	-	30.0
DS flange	4	12.0	0.94	-	40.0
Quoin & Miter Posts					
Web	2	30.0	0.63	-	20.0
Flange	2	12.0	1.00	-	20.0
Block	2	8.0	2.63	-	290.0
		Total =		4320.0	590.0

Table 3-2
Computation of Distance Y

Girder	I_n(in.^{4})	y (in.)	$I_{n.y}$(in.^{5} x 10^6)
G-1	9,000	+374.0	+3.37
G-2	9,000	+272.0	+2.44
G-3	15,000	+200.0	+3.00
G-4	15,000	+128.0	+1.92
G-5	15,000	+ 73.3	+1.10
G-6	15,000	+ 18.5	+0.28
G-7	15,000	+ 36.3	- 0.55
G-8	15,000	- 91.0	- 1.36
G-9	15,000	- 145.8	- 2.18
G-10	15,000	- 200.5	- 3.00
G-11	15,000	- 255.3	- 3.84
G-12	9,000	- 310.0	- 2.79
Σ	162,000		- 1.61

$$A = -\Sigma \frac{T_z}{sR_o hv}$$

$$= -\left(\frac{-11,570 \times 10^6}{18,000 \times 0.0822 \times 684 \times 529} \right) \quad (3\text{-}25)$$

$$= 21.5 \text{ in.}^2$$

For diagonal $L_o U_1$,

$$A = -\left(\frac{9,200 \times 10^6}{18,000 \times 0.0822 \times 684 \times 529} \right)$$

$$= 17.1 \text{ in.}^2$$

Table 3-3
Computation of Distance X

Girder	a(in.^{2})	Y(in.)	Y_n(in.)	ayy_n(in.^{4} x 10^6)
G-1	22.1	+374.0	+384.0	3.17
G-2	22.1	+272.0	+282.0	1.69
G-3	33.9	+200.0	+210.0	1.42
G-4	33.9	+128.0	+138.0	0.60
G-5	33.9	+ 73.3	+ 83.3	0.21
G-6	33.9	+ 18.5	+ 28.5	0.02
G-7	33.9	- 36.3	- 26.3	0.03
G-8	33.9	- 91.0	- 81.0	0.25
G-9	33.9	- 145.8	- 135.8	0.67
G-10	33.9	- 200.5	- 190.5	1.29
G-11	33.9	- 255.3	- 245.3	2.13
G-12	22.1	- 310.0	- 300.0	2.06
			Σ	13.54
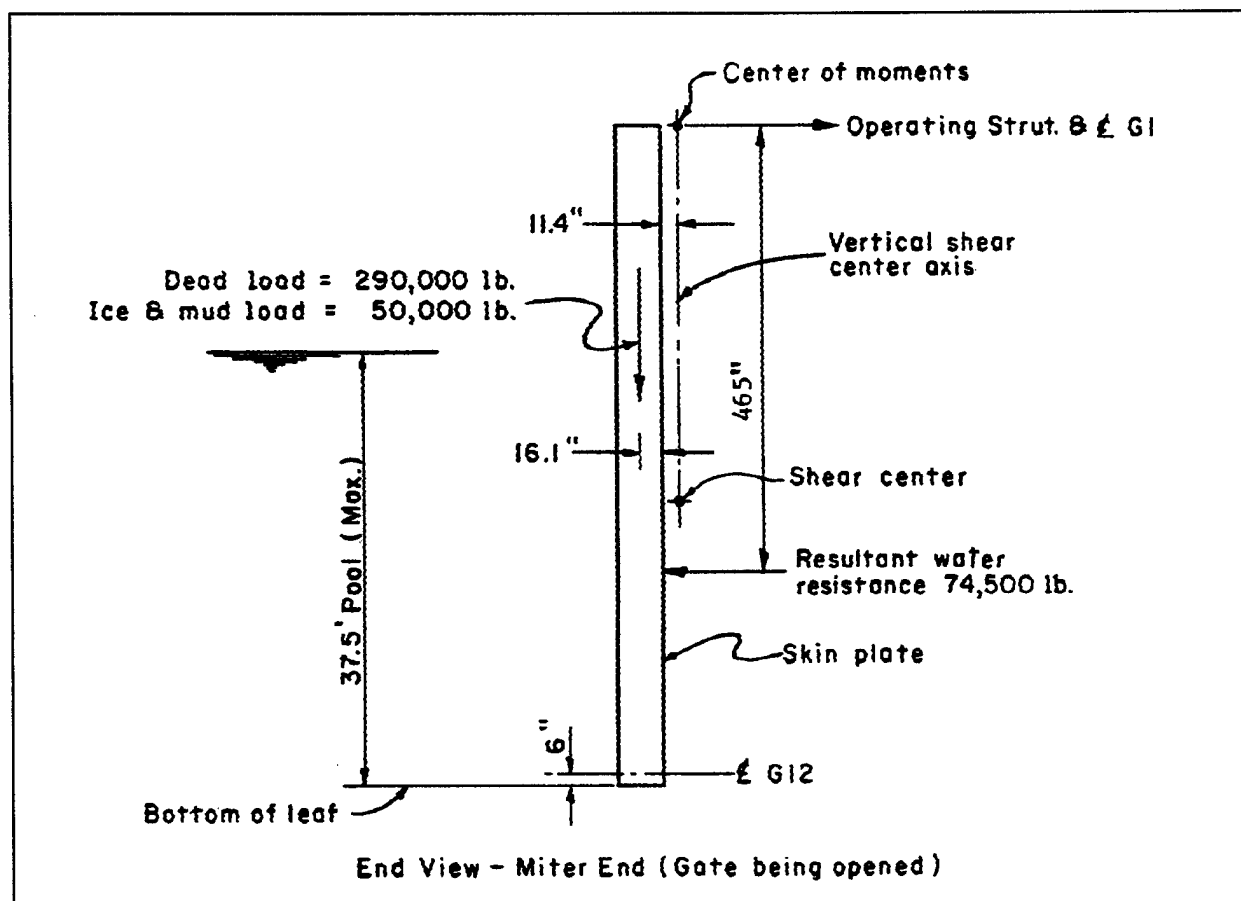
Figure 3-8. Forces acting on leaf being opened

Table 3-4
Computation of Torque Area

Load	Force (lb)	Moment arm (in.)	z (in.)	T_z(in.^{2}lb x 10^6)
Dead load	290,000	27.5[a]	253	-2,020
Ice & mud	50,000	27.5	253	-350
Water	74,500	465.0	265	±9,200[b]

[a] From determinations of shear center and center of gravity for various horizontally framed gates, this arm is approximately 3/4t.
[b] Plus value for gate opening.

For diagonal L_oU_1, the dead load torque is not now included since diagonal U_oL_1 will be prestressed to support this load. The following diagonal sizes will be used throughout the remainder of the design and revised later, if necessary.

$$U_oL_1 - 24.0 \text{ in.}^2 \quad (2 @ 12 \text{ in.}^2)$$

$$L_oU_1 - 18.0 \text{ in.}^2 \quad (2 @ 9 \text{ in.}^2)$$

$$R = \frac{A'}{A + A'} R_o = \pm\frac{22}{A+22} \times 0.822) \quad (3\text{-}13)$$

$$Q = \frac{RR_oEAhv}{L}$$

$$= \frac{R \times 0.0822 \times 29 \times 10^6 \times A \times 684 \times 529}{771}$$

$$= 112 \times 10^7 \times RA$$

Computation of the constant Q is given in Table 3-5.

Table 3-5
Computation of Constant Q

Diagonal	A (in.^{2})	R	Q (in.-lb x 10^6)
U_oL_1	24.0	+0.0393	1,050.
L_oU_1	18.0	-0.0452	910.
		ΣQ =	1,960.

f. Deflection of leaf.

$$\text{Gate opening} \quad \Delta = \frac{\Sigma T_z}{Q_o + \Sigma Q}$$

$$= \frac{9,200 \times 10^6}{(120 + 1,960) \times 10^6} \quad (3\text{-}23)$$

$$= 4.4$$

$$\text{Gate closing} \quad \Delta = \frac{(-9,200 - 350) \times 10^6}{(120 + 1,960) \times 10^6}$$

$$= -4.6$$

g. Prestressed deflections and stresses in diagonals. Prestress deflections are determined in Table 3-6. The minimum numerical values of D (line 3) are the maximum deflections of the leaf. Maximum numerical values of $(D - \Delta)$ are found by solving Equation 3-24.

$$(D - \Delta) = \frac{sL}{RE} = \frac{18,000 \times 771}{R \times 29 \times 10^6} = \frac{0.478}{R}$$

Having the maximum numerical values of $(D - \Delta)$, the maximum values of D are determined and placed in line 5. Values of D (line 6) are then selected between the above limits such that Equation 3-22 is satisfied; that is, $\Sigma(QD)$ must equal +2,020 × 10^{6}in.^{2}lb. Further, to ensure that the diagonals will always be in tension, D should be such that the minimum stress is more than

Table 3-6
Stresses in Diagonals During Normal Operation

Line	Parameter	Positive Diagonal U_oL_1	Negative Diagonal L_oU_1
1	R	+0.0393	-0.0452
2	Q (in.-lb. × 10^6)	1,050	910
3	Minimum numerical value of D (in.)	+4.4	-4.6
4	Maximum numerical value of D-Δ) (in.)	+12.1	-10.6
5	Maxumum numerical value of D (in.)	+7.5	-6.2
6	D (selected value) (in.)	+6.7	-5.5
7	QD (in.^{2}-lb. x 10^6)	+7,030	-5,000

$$\Sigma(QD) = 2,030 \times 10^6 \text{ in.}^2\text{-lb}$$

Line	Operation	Stress, ksi	
8	Gates stationary Δ = 0	9.9	9.4
9	Gates being opened Δ = +4.4	3.4	16.8
10	Gates being closed Δ = +4.6	16.7	1.5

1 kip per in.^{2} Stresses which occur during normal operation of the gate are computed from

$$s = \frac{RE}{L}(D - \Delta) \tag{3-24}$$

and are placed in lines 8, 9, and 10.

From Table 3-6, it is seen that the diagonal sizes chosen are quite satisfactory.

h. Method of prestressing. The turn-of-the-nut method will be used. After the diagonals are made slack, the deflection of the leaf is measured in the field. Since this actual initial deflection is unknown at this time, the theoretical value will be used (with diagonals slack Q - zero).

$$\Delta = \frac{\Sigma T_z + \Sigma Q_D}{Q_o + \Sigma Q} = \frac{\Sigma T_z}{Q_o}$$

$$= \frac{-2,020 \times 10^6}{120 \times 10^6} = -16.8 \text{ in.} \tag{3-21}$$

(1) Diagonal U_oL_1. The slack is removed from this diagonal only and the diagonal is clamped. The required prestress is then obtained by tightening the sleeve nut the following number of turns:

$$N = \frac{nR_o(D - \Delta)}{2}$$

$$= \frac{2.5 \times 0.0822}{2}[+6.7 - (-16.8)]$$

$$= 2.41 \text{ turns} \tag{3-27}$$

The torque required to accomplish this is found from Equation 3-28 after determining the resulting leaf deflection from

$$\Delta = \frac{\Sigma T_z + \Sigma Q_D}{Q_o + \Sigma Q}$$

$$= \frac{(-2{,}020 + 1{,}050 \times 6.7) \times 10^6}{(120 + 1{,}050) \times 10^6} \qquad (3\text{-}21)$$

$$= 4.4 \text{ in.}$$

$$M = \frac{0.18 \; REA_d \, (D - \Delta)}{L}$$

$$= \frac{0.18 \times 0.0393 \times 29 \times 10^6 \times 12 \times 4.75 \, (6.7 - 4.4)}{771}$$

$$= 35{,}000 \text{ in.-lb} \qquad (3\text{-}28)$$

or 490 lb required at the end of a 6-ft wrench. In this option it is assumed that both members of diagonal U_oL are prestressed simultaneously.

(2) Diagonal L_oU_1. The theoretical initial deflection of the leaf for this diagonal is the final leaf deflection of 4.4 in. after prestressing the previous diagonal. To prestress this diagonal the required amount, it is necessary to tighten the nut through the following turns, after first removing the slack.

$$N = \frac{2.75 \, (-0.0822) \, (-5.5 - 4.4)}{2} \qquad (3\text{-}27)$$

$$= 1.12 \text{ turns}$$

This tightening will make the leaf plumb ($\Delta = 0$) and will require a maximum torque of:

$$M = \frac{0.18 \, (-0.0452) \times 29 \times 10^6 \times 9 \times 4.25 \, (-5.5 - 0)}{771}$$

$$= 64{,}000 \text{ in.-lb} \qquad (3\text{-}28)$$

or 900 lb required at the end of a 6-ft wrench.

(3) Plumb/out of plumb. With the completion of this operation, the leaf will nearly always hang plumb. If it does not, the corrected prestress deflection for this diagonal can be found from Equation 3-21 with Δ equal and opposite to the out-of-plumb deflection. This prestress deflection can then be substituted in Equation 3-27 to obtain the corrected number of turns required to make the leaf hang plumb. For instance, for a final out-of-plumb deflection of +1/2 in., the corrected prestress deflections would be found from $\Sigma QD = (\Delta Q_o + \Sigma Q) - (T_z)D.L.$ to be +980 in.^{2}lb $\times$ 10^6. With D for diagonal L_oU_1 maintained at -5.5 in., the D then required for diagonal U_oL_1 would be +5.7 in. and N for this diagonal would become 2.30 turns. The remainder of the computations would be repeated.

3-6. Example 2, Vertically Framed Gate

See Figures 3-9 and 3-10.

a. *Evaluation of A'*. The cross-sectional area of the bottom girder (see Figure 3-10) is 36.7 in^2, the cross-sectional area of any vertical girder is 37.0 in.^{2}, (see Figure 3-9), and the cross-sectional area of the top girder is 112.5 in.^{2}. Therefore, the value of A' (see definition) for all diagonals is
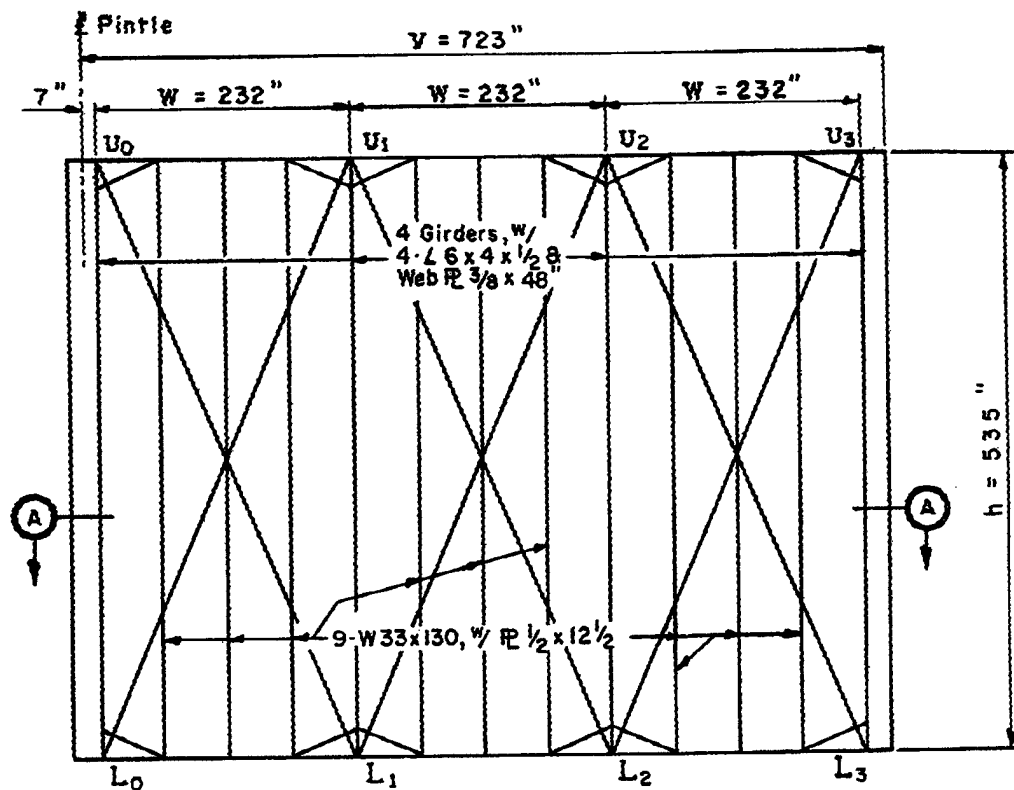
$$A' = (1/20) \, (36.7 + 74.0 + 112.5) = 11.0 \text{ in.}^2$$

b. *Evaluation of R_o, R, and Q*. Since this is an existing lock, the diagonal sizes are fixed.

$$R_o = \pm \frac{2wt}{v(w^2 + h^2)^{\frac{1}{2}}}$$

$$= \pm \frac{2 \times 232t}{723 \, (232^2 + 535^2)^{\frac{1}{2}}} \qquad (3\text{-}11)$$

$$= \pm 0.00110 \, t$$

$$R = \frac{A'}{A + A'} R_o$$

$$= \pm 0.0121 \frac{t}{(A + 11)} \qquad (3\text{-}13)$$

$$= \frac{11}{(A + 11)} R_o$$

Diagonals on both US and DS faces.
Pin-to-pin length of all diagonals is 471 in.
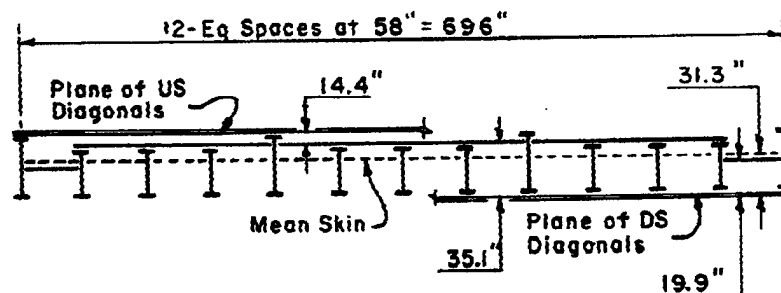
Downstream Elevation

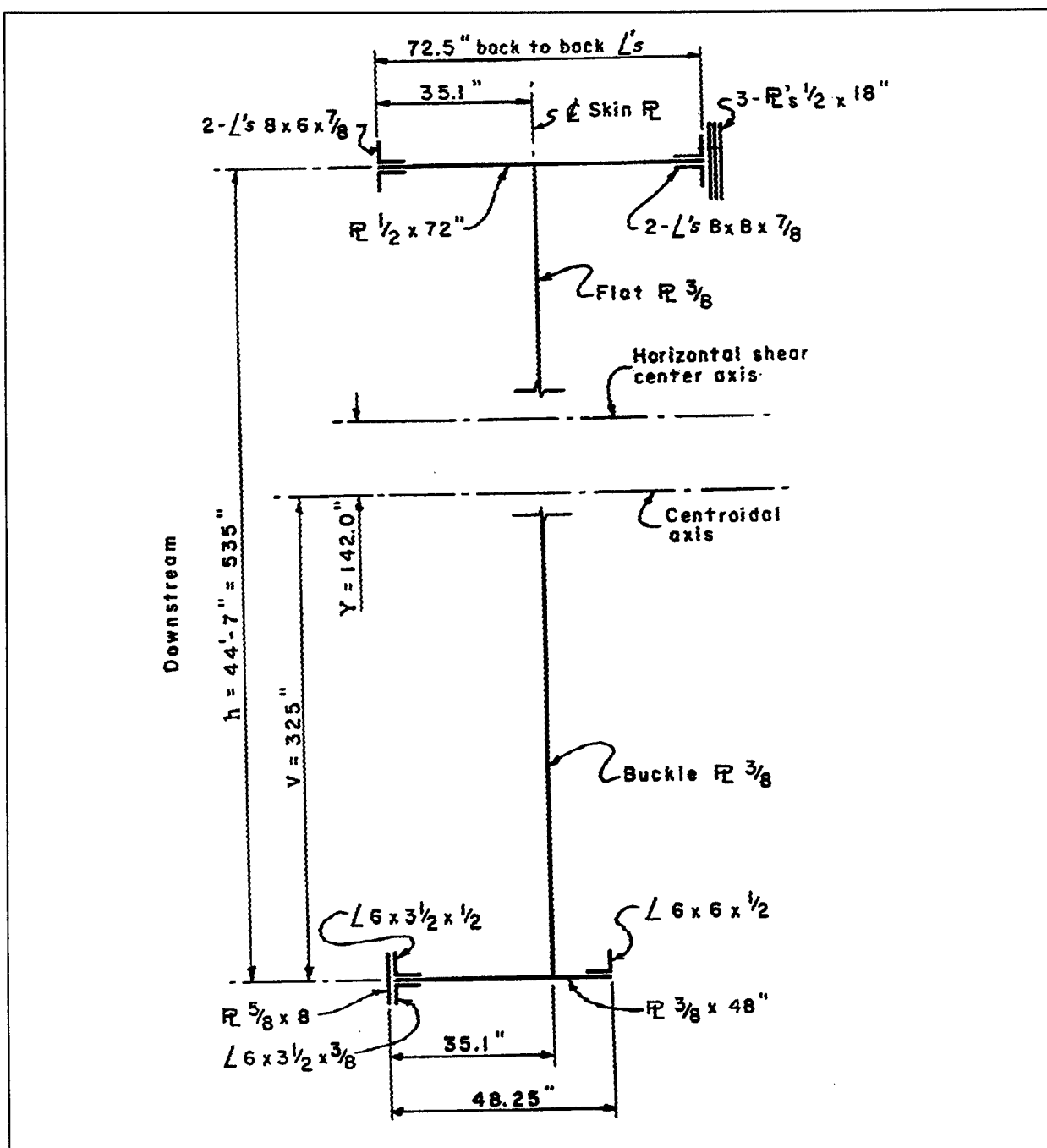Figure 3-9. Schematic drawing of a vertically framed leaf

Figure 3-10. Average vertical section through leaf

$$Q = \frac{RR_o EAhv}{L}$$

$$= \frac{RR_o \times 29 \times 10^6 \times A \times 535 \times 723}{471} \qquad (3\text{-}18)$$

$$= 238 \times 10^8 \times RR_o A$$

Computation of the elasticity constant Q is shown in Table 3-7.

(1) Because all the skin in the end panels is not in the same plane, t (in the end panels) is measured from the mean skin shown in Figure 3-9. (See paragraph 3-4h for the determination of t for skin not in a plane.)

(2) This example provides a good illustration of the inefficiency of past designs. The upstream diagonals are quite ineffective because they are so close to the skin plate. If all the upstream diagonals were omitted (in other words, the number of diagonals cut in half) and the

skin plate placed in their location instead, the leaf would be stiffer and the stresses in the remaining diagonals would be lower. Further, with a flat skin plate, all positive diagonals could have been made the same size and all negative diagonals, another size (for simplification of details and reduction in cost).

c. *Evaluation of* Q_o. (See paragraph 3-4i(2) and Table 3-8.)

$$Q_o = K \times E_s \times \Sigma(J/h + J/v)$$

$$= 4 \times 12 \times 10^6 \left(\frac{310}{3 \times 535} + \frac{700}{3 \times 723} \right) \qquad (3\text{-}26)$$

$$= 25 \times 10^6 \text{in.-lb}$$

d. *Location of shear center.* (See paragraph 3-5c.) Computations for the centroidal axis and the moment of inertia of the vertical section through the leaf (see Figure 3-9) are not shown.

Table 3-7
Computation of Elasticity Constant Q

Diagonal	A (in.^{2})	t (in.)	R_o	R	Q (in.lb $\times 10^6$)
[a] D'stream U_0L_1	10.00	31.5	+0.0347	+0.0182	150.0
[a] D'stream U_1L_2	8.00	35.2	+0.0388	+0.0224	165.0
[a] D'stream U_2L_3	4.50	31.3	+0.0345	+0.0244	90.0
[a] Upstream L_0U_1	4.50	18.3	+0.0202	+0.0143	31.0
[a] Upstream L_1U_2	4.50	14.4	+0.0159	+0.0112	19.0
[a] Upstream L_2U_3	4.50	17.9	+0.0197	+0.0140	30.0
[b] Upstream U_0L_1	10.00	17.2	-0.0189	-0.0099	45.0
[b] Upstream U_1L_2	8.00	13.3	-0.0146	-0.0085	24.0
[b] Upstream U_2L_3	4.50	17.0	-0.0187	-0.0133	27.0
[b] D'stream L_0U_1	4.50	32.6	-0.0359	-0.0255	98.0
[b] D'stream L_1U_2	4.50	36.2	-0.0399	-0.0282	120.0
[b] D'stream L_2U_3	4.50	32.2	-0.0355	-0.0252	96.0
					$\Sigma Q = 895$

[a] Positive diagonals
[b] Negative diagonals

Table 3-8
Computation of Modified Polar Moment of Inertia J

Elements	n No. of Elements	1 (in.)	c (in.)	Horizontal Members	Vertical Members
Horiz. Girders					
U/S flange,	1	18.0	2.38	240	
Web, (Top)	1	72.0	0.50	10	
D/S Flange,	2	14.0	0.88	20	
U/S flange,	1	12.0	0.50	0	
Web, (Bottom)	1	48.0	0.38	0	
D/S flange	1	8.0	1.13	10	
Skin plate	1	535.0	0.38	30	
Vertical Girders					
U/S flange	8	10.0	0.50		10
Intermed. flange	6	7.0	0.38		0
Web	4	48.0	0.38		10
U/S flange	8	10.0	0.50		10
Vertical Beams	9	11.5	1.73		540
US flange	9	31.4	0.58		60
Web	9	11.5	0.86		70
D/S flange					
				Total = 310	700

$y = 325$ in.
$I = 14.3 \times 10^6$in.^{4}

Horizontal shear center axis:

Moment of inertia of:
Top girder = 84,100 in.^{4}

$$Y = \frac{\Sigma(I_n \cdot y)}{\Sigma I_n}$$

$$= \frac{84,100 \times 210 - 12,100 \times 325}{96,200}$$

$$= +142$$

(3-29)

Vertical shear center axis:

Computation of the distance X is shown in Table 3-9.

$$X = -\left[\frac{\Sigma(ayby_n)}{I}\right]$$

$$= -\left(\frac{-69.9 \times 10^6}{14.3 \times 10^6}\right) = +4.9 \text{ in.}$$

(3-30)

e. Load torque areas. (See discussion in paragraph 3-4*i*(3).) The forces which produce twisting of the leaf are shown in Figure 3-11. Again, computations for locating the center of gravity and deadweight of the leaf are not shown. Since this is a 9-ft channel handling only shallow-draft vessels, a water resistance of 30 psf is used.

For dead load: $T_z = -235,000 (10.7 + 4.9) \times 355$
$= -1,300 \times 10^6$in.^{2}-lb

3-25

Table 3-9
Computation of Distance X for Vertically Framed Gate

Girder	a (in.^{2})	b (in.)	y (in.)	y_n (in.)	$ayby_n$ (in.$^5 \times 10^6$)
Top girder - U/S	62.8	+37.4	+210	+ 68	+ 33.5
Top girder - D/S	31.8	- 35.1	+210	+ 68	- 15.9
Bottom girder - U/S	8.2	+13.1	-325	-467	+ 16.3
Bottom girder - D/S	19.5	- 35.1	-325	-467	-103.8

$$\Sigma = - 69.9$$
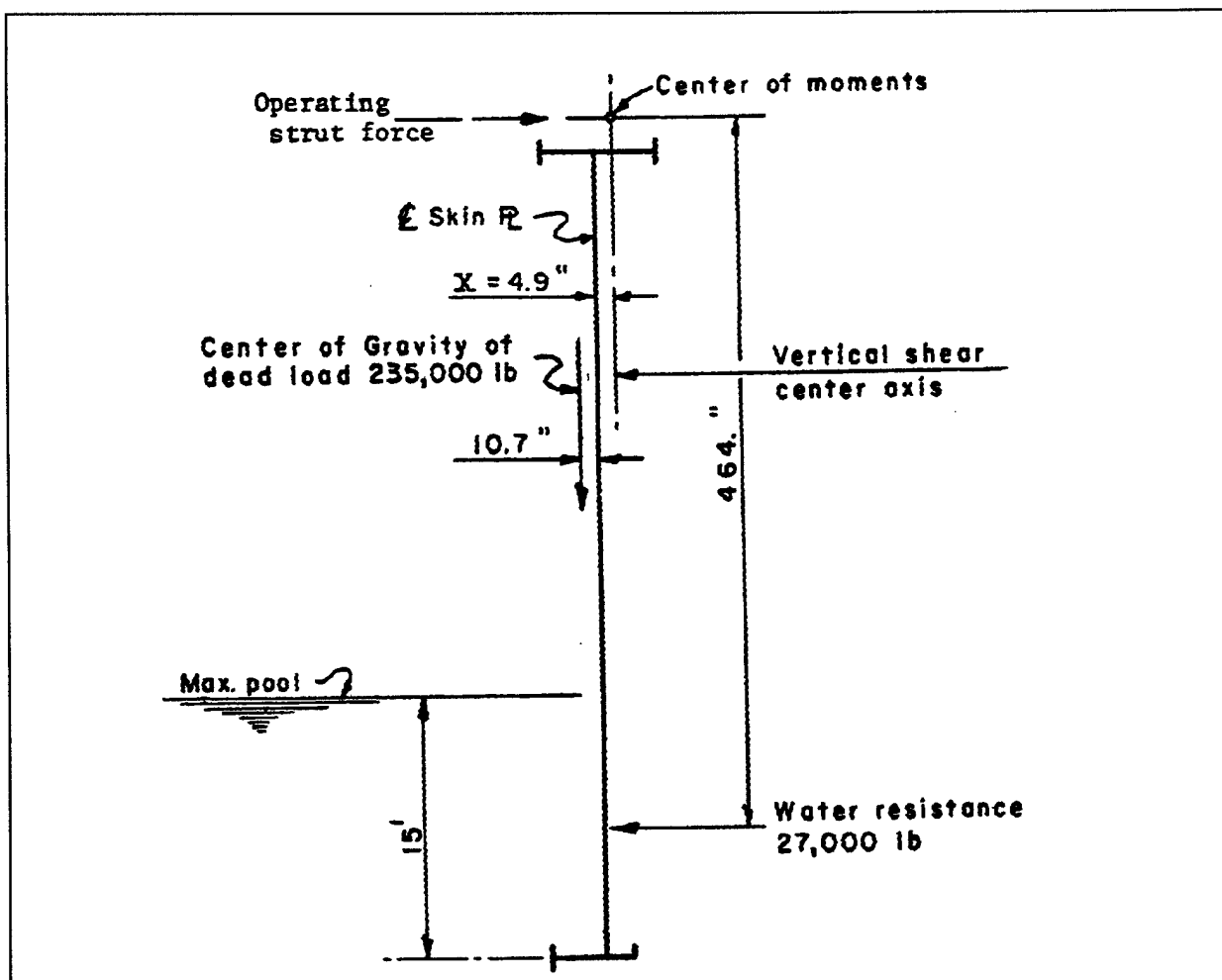
Figure 3-11. Torsional forces on leaf

For live load: $T_z = \pm 27{,}000 \times 464 \times 362$
$$= \pm 4{,}350 \times 10^6 \text{ in.}^2\text{-lb}$$
(positive value for gate opening)

f. Deflection of leaf.

$$\Delta = \frac{\Sigma T_z}{Q_o + \Sigma Q} \tag{3-23}$$

$$= \frac{\pm 4{,}530 \times 10^6}{(25 + 895) \times 10^6} = \pm 4.9 \text{ in.}$$

Where positive value is for gate opening.

g. Prestress deflections and stresses in diagonals. The prestress deflections are determined in Table 3-10. The minimum numerical values of D (column 4) are the maximum deflections of the leaf. Maximum numerical values of $(D - \Delta)$ are found by solving Equation 3-24

$$(D - \Delta) \text{ max} = \frac{sL}{RE}$$

$$= \frac{18{,}000 \times 471}{R \times 29 \times 10^6} = \frac{0.292}{R}$$

Having the maximum numerical values of $(D - \Delta)$, the maximum numerical values of D are determined and placed in column 6. Values of D (column 7) are then selected such that Equation 3-22 is satisfied; that is, ΣQD must equal $+1{,}300 \times 10^6$ in.^{2}-lb. Because all but the top 10 ft of the skin consists of buckle plates (see paragraph 3-4i(4)), an attempt is made to have the diagonals carry as much of the vertical dead load shear as possible. Therefore, values of D are made as large as possible for the diagonals extending downward toward the miter end, and as small as possible for the other diagonals. Further, to ensure that the diagonals are always in tension, D should also be such that the minimum stress is more than 1,000 psi. The unit stresses in the diagonals are found from

$$s = \frac{RE}{L}(D - \Delta) \tag{3-24}$$

Before computing normal stresses (columns 10, 11, and 12), the stresses which occur during the prestressing operation are computed (column 9) as a check on the value of D. The twist-of-the-leaf method for prestressing

is used. Because of the large value of D for some of the negative diagonals, it is best to prestress all negative diagonals first.

h. Dead load shear in skin: (buckle plates). Prestressing of many gates in the Rock Island District has proved that buckle plates can support the shear imposed on them during and after the prestressing operation without any apparent distress. However, it is still considered desirable to have the diagonals carry as much of the vertical dead load shear as possible. If the skin had been flat plate, this consideration would have been omitted. In Table 3-11 the dead load shear remaining in the skin (buckle plates) is determined.

i. Method of prestressing. The twist-of-the-leaf method will be used as outlined in paragraph 3-4j(1). The maximum force will be required when the leaf is deflected +10.0 in. against the action of the negative diagonals (which are prestressed, in this case, first).

$$P = \frac{\Delta (Q_o + \Sigma Q) - \Sigma QD - (\Sigma T_z)DL}{hv}$$

$$= \frac{[+10.0 (25 + 410) - (2{,}620) - (-1{,}300)] \times 10^6}{535 \times 723}$$

$$= 21{,}000 \text{ lb}$$

Upon completion of this prestressing operation, the leaf is very rarely out of plumb. Should it be, however, the corrected prestress deflections can be found from Equation 3-21 with Δ equal and opposite to the out-of-plumb deflection, as follows.

$$\Sigma QD = \Delta (Q_o + \Sigma Q) - (\Sigma T_z)_{DL}$$

In this example, for a final out-of-plumb deflection of +½ in., revised values of D would be selected to make ΣQD equal to $+840. \times 10^6$ in.^{2}-lb. The leaf would then hang plumb. Repeat computations, if necessary.

3-7. Vertical Paneling of Leaf

The previous design applies to miter gate leaves that are divided into panels (not necessarily equal) longitudinally. With a slight modification of the term R_o the design is extended to apply to leaves that are divided into panels vertically as well as longitudinally. Figure 3-12 shows the most general arrangement of paneling. In practice, an effort would be made to make the panel heights and widths the same. To design the diagonals use

Table 3-10
Computation of Diagonal Stresses

TABLE 3 - 10 COMPUTATION OF DIAGONAL STRESSES

#		POS. DIAGONALS						NEG. DIAGONALS					
		D.S. U_0L_1	D.S. U_1L_2	D.S. U_2L_3	U.S. L_0U_1	U.S. L_1U_2	U.S. L_2U_3	U.S. U_0L_1	U.S. U_1L_2	U.S. U_2L_3	D.S. L_0U_1	D.S. L_1U_2	D.S. L_2U_3
1	DIAGONAL												
2	R	+0.0182	+0.0224	+0.0244	+0.0143	+0.0112	+0.0140	-0.0099	-0.0085	-0.0133	-0.0255	-0.0282	-0.0252
3	Q IN. - LB X 10^6	150	165	90	31	19	30	45	24	27	98	120	96
4	MINIMUM NUMERICAL VALUE OF D	+4.9	+4.9	+4.9	+4.9	+4.9	+4.9	-4.9	-4.9	-4.9	-4.9	-4.9	-4.9
5	MAXIMUM NUMERICAL VALUE OF (D - Δ)	+16.1	+13.0	+12.0	+20.4	+26.1	+20.8	-29.5	-34.3	-22.0	-11.4	-10.3	-11.6
6	MAXIMUM NUMERICAL VALUE OF D	+11.2	+8.1	+7.1	+15.5	+21.2	+15.9	-24.6	-29.4	-17.1	-6.5	-5.4	-6.7
7	D	+10.0	+7.5	+6.5	+7.5	+7.5	+7.5	-12.0	-12.0	-5.25	-6.25	-5.25	-5.25
8	QD IN.^{2} - LB. X 10^6	+1500	+1240	+590	+600			-830		-140	-1,650		
9	DURING PRESTRESSING Δ = + 10.0 IN.	PRESTRESSED LAST						13,400	11,500	12,500	23,900	26,400 a	23,600
10	GATE STATIONARY Δ = 0	11,200	10,300	9,800	6,600	5,200	6,500	7,300	6,300	4,300	8,300	9,100	3,100
11	GATE BEING OPENED Δ = + 4.9 IN.	5,700	3,600	2,400	2,300	1,800	2,200	10,300	8,800	8,300	15,900	17,600	15,700
12	GATE BEING CLOSED Δ = -4.9 IN.	16,700	17,100	17,100	10,900	8,500	10,700	4,300	3,700	300	600	600	600

QD = +1,310

(Rows 9–12 left column: STRESS, LB / SQ. IN.)

a TOO HIGH, BUT INHERENT IN THIS EXISTING GATE.

Table 3-11
Computation of Dead Load Shear in Buckle Plates

Panel	Diagonal	A (in.²)	s (lb/in.²)	As (lb)	$\Sigma(As \frac{h}{L})$ (lb)	Panel	Skin
0-1	DSU_oL_1	10.0	11,200	+112,000			
	USU_oL_1	10.0	7,300	+ 73,000			
	USL_oU_1	4.5	6,600	- 29,000	+119,000 lb	- 196,000 lb	+77,000 lb
	DSL_oU_1	4.5	8,300	- 37,000			
1-2	DSU_1L_2	8.0	10,300	+ 82,000			
	USU_1L_2	8.0	6,300	+ 50,000			
	USL_1U_2	4.5	5,200	- 23,000	+ 68,000	+117,000 lb	+49,000 lb
	DSL_1U_2	4.5	9,100	- 41,000			
2-3	DSU_2L_3	4.5	9,800	+ 44,000			
	USU_2L_3	4.5	4,300	+ 19,000			+41,000 lb
	USL_2U_3	4.5	6,500	- 29,000	- 2,000	- 39,000 lb	
	DSL_2U_3	4.5	8,100	- 36,000			
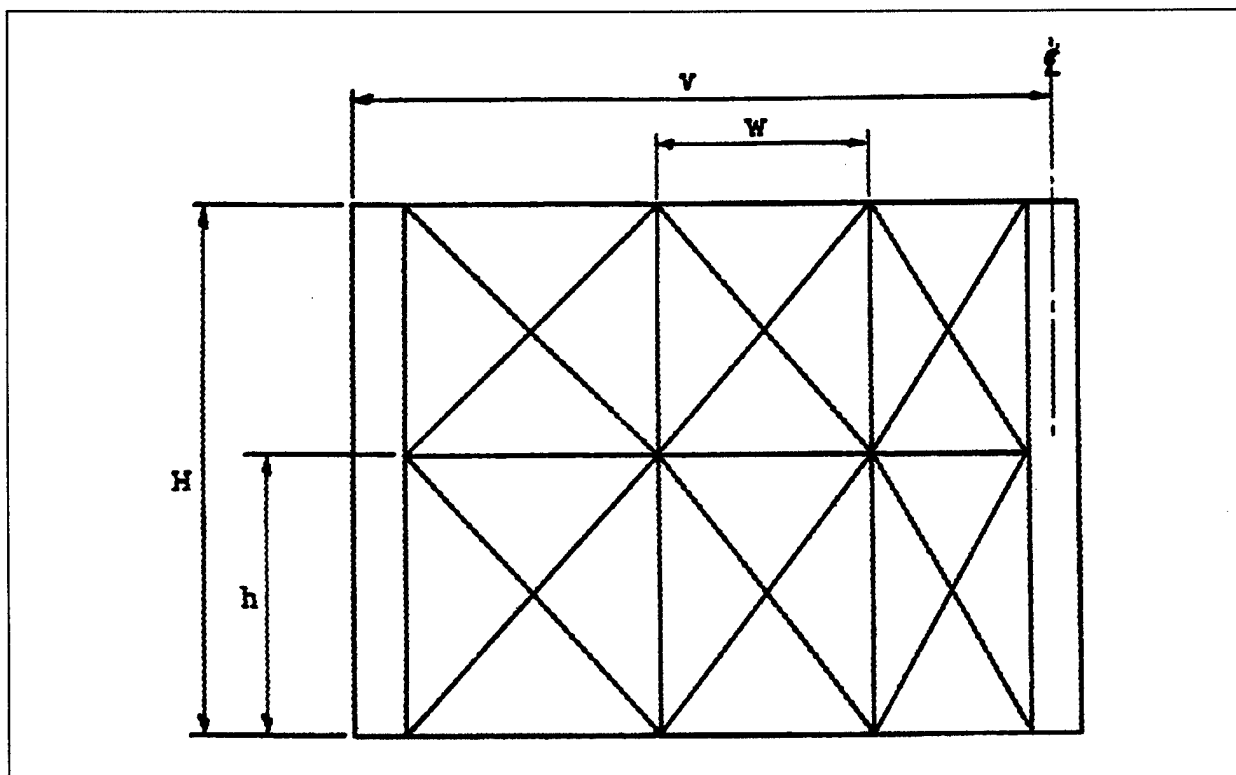
Figure 3-12. Vertical and longitudinal arrangement of leaf panels

$$R_o = \pm \left(\frac{2w \cdot h \cdot t}{H \cdot v \cdot (w^2 + h^2)^{1/2}} \right) \qquad (3\text{-}11)'$$

This value of R_o replaces that given in Equation 3-11, being a more general expression. It is seen that for a value of $h = H$ (no vertical paneling) Equation 3-11' reverts to Equation 3-11. With the above value of R_o, all the other expressions and the method of analysis remain identical to that previously outlined.

3-8. Derivation of Equation 3-11'

The general value of R_o can be found as follows. (Refer to paragraph 3-4d). Let d = deflection of panel; other symbols are as defined previously. Figure 3-13 illustrates the displacements of points of a vertical divided panel.

Let δ_o = change in length of any diagonal

$$\delta_o = \left(\frac{d}{w} t \cos \alpha \right) + \left(\frac{d}{h} t \sin \alpha \right)$$

$$= \frac{d\,t}{w} \left[\frac{w}{(w^2 + h^2)^{1/2}} \right]$$

(See Figure 3-13)

$$+ \frac{d\,t}{w} \left[\frac{h}{(w^2 + h^2)^{1/2}} \right]$$

$$\delta_o = \left[\frac{2dt}{(w^2 + h^2)^{1/2}} \right]$$

Where h and d are the height and deflection of *one* panel

then

$$r_o = \frac{\delta_o}{d} = \pm \left[\frac{2t}{(w^2 + h^2)^{1/2}} \right]$$

The relation between the deflection of the panel and the leaf becomes

$$d = \left(\frac{w}{v} \right) \left(\frac{h}{H} \right) \Delta \quad \text{or} \quad \Delta = \left(\frac{v}{w} \right) \left(\frac{H}{h} \right) d$$

$$R_o = \frac{\delta_o}{\Delta} = \left[\frac{2dt}{(w^2 + h^2)^{1/2}} \right] \left[\frac{1}{\left(\frac{v}{w} \right) \left(\frac{H}{h} \right) d} \right] \qquad (3\text{-}11)'$$

$$R_o = \pm \left[\frac{2w\,h\,t}{H\,v\,(w^2 + h^2)^{1/2}} \right]$$

The remainder of the expressions are the same as before, for distance

$$R_o = \frac{\delta}{\Delta} = \frac{r\,d}{\left(\frac{v}{w} \right) \left(\frac{H}{h} \right) d} = \left(\frac{w}{v} \right) \left(\frac{h}{H} \right) r$$

$$= \left(\frac{w}{v} \right) \left(\frac{h}{H} \right) \left(\frac{A'}{A + A'} \right)$$

$$R_o = \left(\frac{w}{v} \right) \left(\frac{h}{H} \right) \left(\frac{A'}{A + A'} \right) \pm \left(\frac{2t}{(w^2 + h^2)^{1/2}} \right)$$

Therefore

$$R_o = \pm \left[\frac{2w\,h\,t}{H\,v\,(w^2 + h^2)^{1/2}} \right] \left(\frac{A'}{A + A'} \right)$$

$$= R_o \left(\frac{A'}{A + A'} \right)$$

In similar manner it can be shown that the expressions for Q and Q_0 (Equations 3-18 and 3-26, respectively) still apply with H substituted for h.

3-9. Temporal Hydraulic Loads

The effect of temporal hydraulic loads on the miter gate diagonal design will be evaluated at each lock with appropriate conditions selected for the design. A minimum temporal hydraulic load of 1.25 ft (with a period exceeding 30 sec) will be used for gate diagonal design if it governs, with a leaf submergence corresponding to
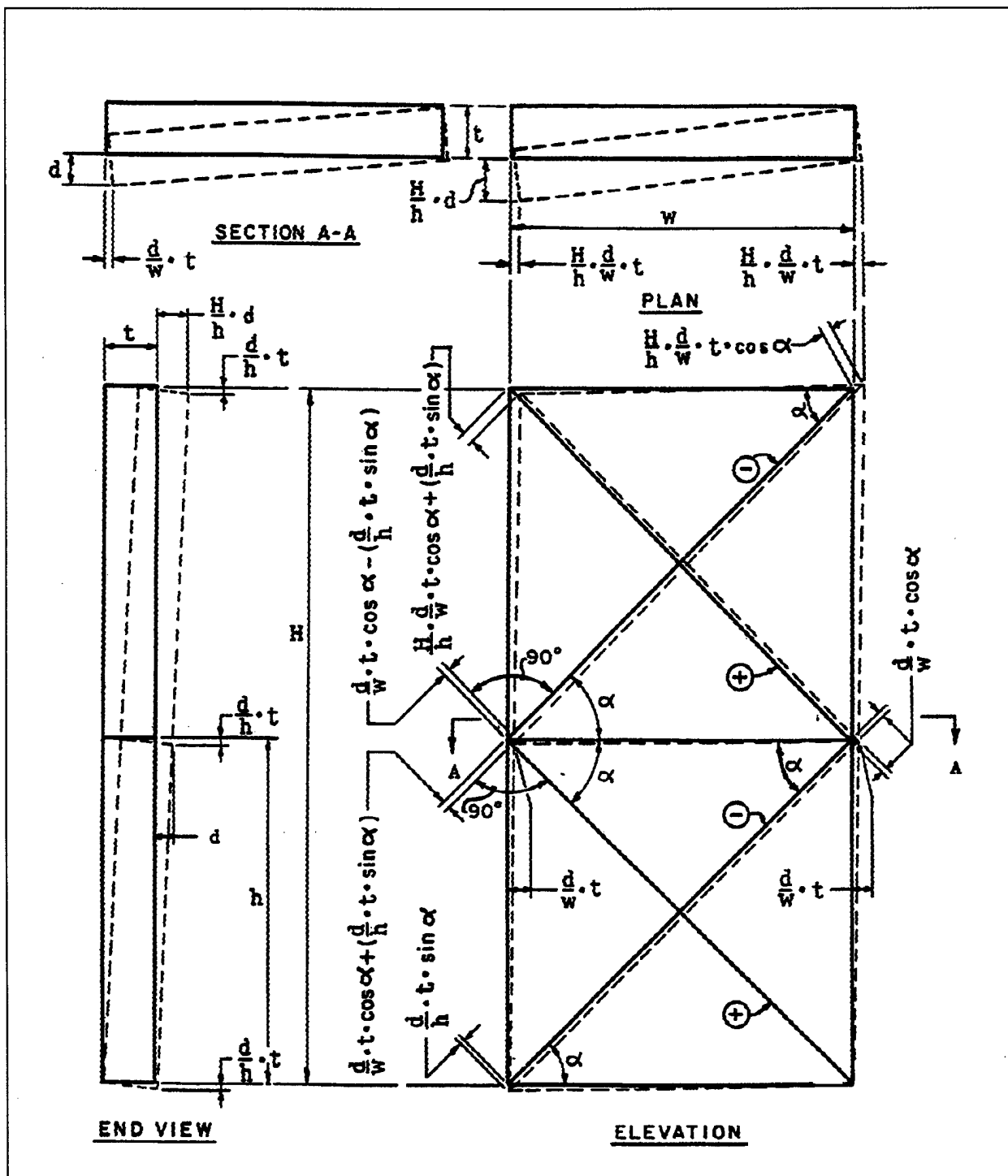
Figure 3-13. Displacement of points of a vertical divided panel

normal navigation pool conditions. For this load condition, a 33-1/3 percent overstress is allowed for diagonal design. Temporal hydraulic loads in the lock chamber and/or lock approaches may be caused singly or in combination by the following:

 a. Wind waves and setup.

 b. Ship waves.

 c. Propeller wash.

 d. Lock overfill and/or overempty.

 e. Lock upstream intake and downstream exit discharges.

 f. Landslide waves.

 g. Tributary and/or distributary flow near lock.

 h. Surges and reflected waves in canals.

 i. Seiches.

 j. Changes in spillway or powerhouse discharges.

 k. Tides.

3-10. Procedure for Prestressing Diagonals

 a. The following steps establish a procedure for prestressing diagonals. There are different procedures for stressing diagonals, this being just one. Use Figure 3-14 with this procedure.

 (1) With all diagonals slack, adjust anchorage bars so quoin end is plumb and bottom girder is horizontal. Pintle shoe shall be fully seated against the back of the pintle base.

 (2) Lubricate the nuts on the diagonals so they can turn easily.

 (3) Place rosettes for strain gages on all diagonals a minimum of 20 hours before prestressing unless an approved quick-setting cement is used.

 (4) Without the restraint of any guys or jacks, the leaf will deflect in a negative direction under its own dead load weight. Measure this deflection.

 (5) Guy the leaf at its miter end to the tieback anchor and place jacks at the miter end.

 (6) Jack the miter end away from the wall until the leaf has a deflection equal to D_1.

 (7) Hold the deflection and tighten diagonals 1 and 3. Tighten these diagonals so that there is no horizontal bow. Do not attempt to remove all vertical sag.

 (8) Tighten diagonals 2 and 4.

 (9) Proceed with the jacking until a deflection D_2 is obtained. During this operation do not change the adjustment of diagonals 1 and 3. However, continue tightening diagonals 2 and 4 until there is a slight tension in the members when the leaf is in its final deflection position.
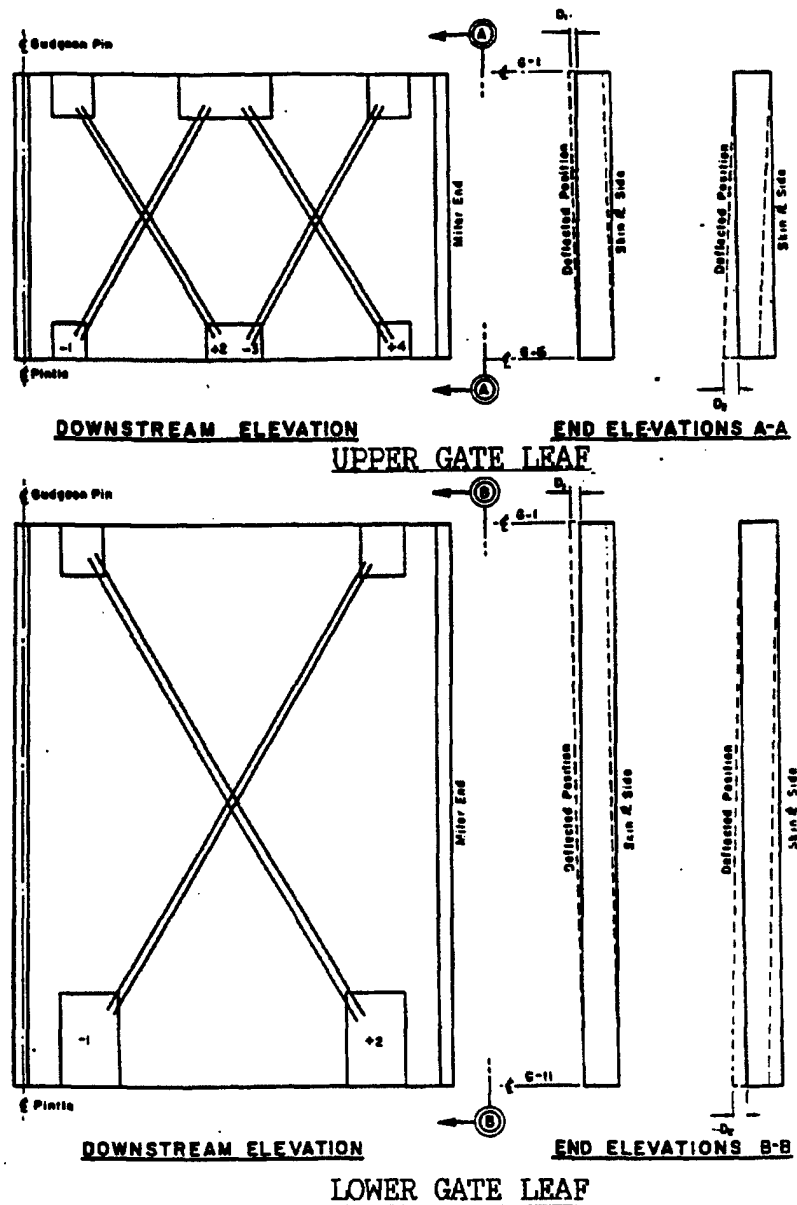
 (10) During the prestressing operation use a strain gage to determine the stress in the diagonals. The maximum allowable stress shall be $0.75F_y$.

 (11) After the final adjustments of the diagonals remove the guys and jacks. The leaf should return to the plumb position. A deflection $\pm1/4$ in. will be permitted in the lower leaf and $\pm1/8$ in. on the upper leaf. A larger tolerance is allowed for the lower leaf because it is much taller than the upper leaf.

 (12) Final minimum and maximum stresses, unless otherwise approved by the Contracting Officer, shall be $0.45F_y$ minimum and $0.55F_y$ maximum for all diagonals.

3-11. New Information on Diagonal Design

 a. New preliminary information has been gained through the finite element study made by Drs. L. Z. Emkin, K. M. Will, and B. J. Goodno of the Georgia Institute of Technology regarding torque tubes and leaf stiffness (USAEWES 1987). For all current gates designed with the 2.5-ft differential head, it appears that the values arrived at through the finite element analysis of Bankhead Lock lower gate in Tuscaloosa, AL, are realistic. This includes the values of leaf stiffness without diagonals, with diagonals, and with horizontal top and bottom torque tubes. These values are only a recommendation and consideration should be given to any variation in leaf configuration and modifications made to adjust the design factors accordingly.

DOWNSTREAM ELEVATION   END ELEVATIONS A-A

UPPER GATE LEAF

DOWNSTREAM ELEVATION   END ELEVATIONS B-B

LOWER GATE LEAF

NOTE:

A deflection of the leaf is defined as a twisting of the leaf such that the miter end is out of plumb. A positive deflection of the leaf is one in which the top of the miter end is moved upstream relative to the bottom. The magnitude of the deflection is the amount by which the top of the miter end is out of plumb, as shown in the figure.

When any diagonals are tightened, they shall be taken up just to the point where all of the slack is removed and a very slight tension exists. Care shall be exercised that the amount of this initial tension is as small as possible. The slack shall be considered to be removed when the diagonal does not bow in or out from the leaf. No attempt shall be made to remove the slight vertical sag which will always exist in the diagonal because of its dead weight.

Figure 3-14. Methods for prestressing diagonal

b. The use of top and bottom torque tubes is suggested as a suitable means of increasing leaf stiffness, although it appears that the conventional method of prestressing by twisting the leaves with a jack may need to be altered. On the Oliver Lock in Tuscaloosa, AL, where the torque tubes were used and diagonals sized for surge loading, it appeared that the twist-of-the-leaf method of prestressing the diagonals had about reached its maximum. Due to the increased leaf stiffness and corresponding jack capacity ($\pm$ 150 tons), it appeared that damage to the leaf, such as localized buckling of plates, excessive deflection of the quoin post, damage to the grease seals, pintle, pintle socket, etc., could be imminent.

c. The values representing leaf stiffness for this particular study were determined to be:

Q_o = stiffness factor of leaves without diagonals

Q_d = stiffness factor of diagonals

Q_t = stiffness factor of top and bottom torque tubes (One 6-ft girder space at top and one 4-ft girder space at bottom)

$$Q_d = 2.4Q_o$$

$$Q_t = Q_o$$

d. It is recommended that consideration be given to prestressing new gate leaves with torque tubes by turning the nuts on the ends of the diagonals and using suitable means to prevent twisting of the diagonals. This would simplify the prestressing and reduce the risk of damage to the gate leaves as well as reduce the risk to personnel. There may be commercial sources that have equipment available that could be readily adapted to this means of prestressing, as has been the case in prestressing the anchor bolts of the embedded anchorage.

e. Additional studies are needed to advance the understanding of miter gate leaf stiffness. Significant factors are dead load deflection, jack loads, if used, strain gage readings, problems encountered, alignment of gudgeon pin over pintle, and any other information thought to possibly be pertinent. For additional information see USAEWES (1987).

Chapter 4
Sector Gates

4-1. Sector Gates

a. Skin plate and vertical ribs.

(1) Skin plate. The skin plate is designed as a continuous member supported by vertical angles of tees, with the calculated thickness being increased by one-sixteenth for corrosion loss. Normally, 3/8-in. total thickness or a design thickness of 5/16 in. is sufficient for the entire height of the gate. The allowable stress is 0.50F for basic loading conditions with a permissible increase of one-third for abnormal loading conditions. The edge of the skin plate should not be turned back on a radius to the horizontal beam. (See Plates B-34 through B-36 for additional information.)

(2) Vertical ribs. The skin plate is attached to vertical ribs, usually angles or tees, by continuous welds. These ribs are designed as continuous members supported by the horizontal beams. The skin plate is considered as an effective part of the vertical ribs, with the effective width of skin plate determined according to the AISC specifications. The minimum depth of ribs should be 8 in. to facilitate painting and maintenance, with design loads consisting of water load only.

b. Horizontal beams. The normal gate leaf has three horizontal beams supporting the vertical ribs and skin plate. Each beam is designed for water load and a combined water and boat load. The minimum depth of horizontal beams is 2 ft-0 in. out-to-out of flanges. The beam is designed as a continuous member supported by the horizontal struts and braces at midpoint between the struts. The curve of the beam can be neglected, with the length used for design equal to the arc length along the center line of the beam.

(1) In order to reduce the effect of dead-load eccentricity on the horizontal beams, the vertical members of the center and recess-side vertical trusses may be framed into the webs of these beams as shown in Section A-A, Plate B-34. The vertical member of the channel-side vertical truss should be attached to the downstream flanges of the horizontal beams as shown in Plan, Plate B-34, to reduce operating forces required during opening of the sector gate under reversed head conditions. Based on model test results published in Technical Report H-70-2 and Appendix A to this report (see USAEWES

1970, 1971) the framing method described above is recommended for new sector gates.

(2) Numerous existing sector gates are framed as shown in Plate B-35 where horizontal ribs are used to support the skin plate. The horizontal beams consist of straight members, with a length equal to the chord length determined by one-half the interior angle of the gate leaf. The beam is assumed to be a continuous beam of two equal spans, with the center support being braces from the horizontal struts. This type of framing is not recommended for new construction. The boat load applied to members of the leaf normally consists of 125,000 lb applied as a single concentrated force.

c. Frames. The basic sector gate leaf frame consists of three horizontal trusses and three vertical trusses, with horizontal and vertical trusses having some common members. The top and center horizontal frame, consisting of three horizontal struts and related bracing, forms a truss that is designed for water and boat load, with the concentrated boat load of 125,000 lb being applied at any point on the horizontal beam and at any panel point on the canal side of the truss. The bottom frame, or horizontal truss, is designed for water load only, assuming no boat impact at this level.

(1) The vertical trusses are designed for dead load and boat load, with the concentrated boat load of 125,000 lb being applied at the top corner and the center panel points. The vertical trusses are also designed for a combination of dead load and concentrated boat load applied at the panel points on the canal side of the leaf, with the boat load applied at the elevation of the top frame or the center panel point. The top horizontal members of the channel and recess side vertical trusses are also designed to support the walkway loads.

(2) The interior angle of the horizontal frames can vary from 60 to 70 deg, with the 70-deg angle preferred for 84-ft locks and larger.

(3) Rather than segmenting the gate leaf into horizontal and vertical trusses necessary for a manual solution, it is now practical to design and analyze sector gates as three-dimensional space frames utilizing available computer programs.

d. Hinge assembly. The hinge bracket and the hinge bracket support are made of cast steel or a weldment. The hinge bracket support is connected to the lock wall with bolts, prestressed to slightly more than the maximum

tension load obtained from dead load and the maximum reverse head.

(1) The adjustment of the hinge assembly is provided between the embedded hinge bracket support and the hinge bracket section containing the pin barrel. Shims are used to adjust the gate leaf both horizontally and transverse to the axis of the lock. The bolts should extend into the concrete a sufficient depth to transfer the gate leaf load to the concrete, keeping the stress in the concrete within the range of 600 psi. The bolts should have an anchor frame or other positive means of transferring the forces to the concrete, assuming all of the transfer is made through bearing on the frame and none through bond on the bolts. The pin barrel segment of the hinge bracket should be designed as a curved beam similar in analysis to the gudgeon pin barrel described in paragraph 3-5 on horizontally framed gates. The pin barrel should be provided with a bronze bushing, with the bearing stress kept below 1,500 psi.

(2) The hinge pin may be made of forged steel or corrosion-resisting steel, depending on the location of the lock in relation to corrosive elements. Suitable means of lubricating the pin shall be provided either through the pin or with a grease fitting through the pin barrel and bushing. (See Plates B-37 and B-38 for suggested details.)

e. Pintle assembly.

(1) Pintle. The spherical pintle has proved to be the most satisfactory type for sector gates. This type of pintle has the advantage of allowing the gate leaf to tilt slightly without binding and also facilitates the replacement of the gate leaf after it has been removed for maintenance or repair. The pintle is designed for the maximum reaction, consisting of the combined water, boat, and gate dead loads.

(a) Corrosion-resisting steel is indicated by past design to be the most suitable material for the pintle where salt or brackish water is encountered.

(b) The pintle shaft, the cylindrical shaped lower segment of the pintle, extending 1 ft 3 in. to 2 ft 1 in. below the curved surface of the pintle, fits into a recess in the pintle base. This section of the pintle is designed for shear and moment as well as bearing on the pintle based between the pintle shaft and pintle base. The end of the pintle shaft is a flat surface that bears directly on the bottom of the recess in the pintle base.

(c) A seal should be provided at the lower edge of the pintle bushing to seal between the bushing and the pintle shaft.

(2) Pintle bushing. The pintle bushing, made of bronze, Alloy 913, Federal Specification QQ-C-390B, is made in two parts, with the plane of the vertical joint placed at 90 deg to the horizontal reaction of the gate. Grease grooves are provided in the bushing along with a suitable means of lubrication. The bushing is so connected to the pintle socket so that rotation between the socket and bushing is eliminated.

(3) Pintle socket. The pintle socket is made of cast steel and is the common point of intersection of the vertical pipe column between the pintle and hinge pin, the lower horizontal struts, and the diagonal chord members of the vertical trusses. The connections of members to the pintle housing are normally made by welding.

(4) Pintle base and anchorage.

(a) The pintle base and anchorage have the same function as the pintle base of miter gates, that is to transfer the horizontal and vertical forces of the gate leaf to the mass concrete. The pintle shaft fits into a recess in the pintle base, and through a combination of direct stress, bending, and shear, the force is transferred from the pintle to the pintle base. The base, in turn, transfers the force into the concrete. A grillage of small beams, normally in the range of an 8-in.-wide flange, is used to transfer the shear and distribute the bearing into the concrete. Anchor bolts are placed in first-pour concrete with the base placed in second pour. The base may be made of cast steel or a built-up weldment. In some cases, anchor bolts, prestressed to compensate for slightly more than the design forces, may be used to hold the pintle base in contact with the concrete. These bolts will be so located and prestressed that a compressive force will exist between all parts of the pintle base and the concrete under all loading conditions. Where prestressed bolts are used the grillage of beams may be eliminated. See Plate B-37 for typical details of pintle and pintle base.

(b) An alternate pintle anchorage design and details may be used as shown in Plate B-38. This design eliminates the grillage beams and assumes that the concrete in contact with the pintle pedestal base is not stressed. The pintle forces (direct stress, bending, and shear) are transmitted into the concrete through the anchor bolts.

f. Seals. The vertical seals on sector gates usually consist of a pair of 3-seals for the gate closure at the center of the lock and a single 3-seal attached to the corner of the gate recess. The seals at the gate closure, with one seal on each leaf, are presently 1/8 in. each seal, for a total of 1/4 in. to assure a minimum amount of leakage when the gate is closed. The recess seal is also set so as to have 1/4-in. compression when the gate is closed. On the recess seal the vertical plate, or angle, at 90 deg to the skin plate, should not extend over 6 in. from the skin plate and a lesser extension is preferable. The bottom seal utilizes an offset "J" seal, with the bulb offset upstream, or away from the convex side of the skin plate. Normal procedure is for the corner, where the bottom seal meets the vertical seal at the miter point, to be fabricated integrally with the bottom seal. (See Plate B-36 for typical details of all seals.)

g. Walkway. Access around the perimeter of the gate leaf and across the lock is provided by walkways mounted on top of the gates. On the recess and skin plate sides the overall width of walkway should be 3 ft 0 in., with 2 ft 8 in. center-to-center of rails. On the channel side, where a greater width is necessary for the transfer of maintenance equipment, the overall width should be 4 ft 0 in., with 3 ft 8 in. center-to-center rails. The dimensions given are for normal conditions and may be varied for unusual circumstances. Design loads should be 100 psf for the recess and skin plate walkway and 150 psf for the channel-side walkway. Grating is preferred over the raised pattern floor plates unless special circumstances warrant the use of plate. When grating is selected, type II, hot-dip galvanized after fabrication, should be used for most applications, with a minimum depth of 1-1/4 in. for bearing bars. Grating panels should be made in convenient size panels for installation and removal. Where raised pattern floor plate is used instead of grating, consideration should be given to hot-dip galvanizing for corrosion resistance and minimum maintenance. Handrail should be provided for all walkways, using 2-in. diameter extra-strong post with 2-in. standard pipe rail in conformance with paragraph 2-1*n*. Where special loading conditions are present the size of rail and post may be varied accordingly. Generally, the railing should be removable and made in convenient size panels to facilitate removal without equipment.

h. Fenders, lifting supports, and gate stops.

(1) Fenders. Timber fenders should be utilized on the canal side of all gate leaves to facilitate the distribution and absorption of barge or boat impact. The usual fender system is of 8-in. by 12-in. white oak timbers bolted to vertical beams, which in turn are connected to horizontal beams or girders. The horizontal beams are connected to the vertical members of the canal-side vertical truss. The timber should be surfaced all four sides, with bolts recessed into the timber a minimum of 1 in. The minimum size bolts used to support the timbers should be 3/4 in. in diameter. Under normal circumstances the horizontal timbers should be spaced 2 ft 0 in. on center, with the top timber placed on the center line of the top horizontal strut. The timber protection system should extend to or slightly below the minimum water level to be encountered during operation.

(2) Lifting supports.

(a) Jacking pads should be provided on the bottom of the gate leaf, located at panel points of the vertical trusses. The pads should be so located that the full weight of the gate can be supported by the pads while maintaining the gate in a stable position. A minimum of three pads should be used on each leaf.

(b) Lifting lugs on top of the gate should be considered for complete removal of the gate from the lock. These lugs should be so located that a standard three-leg bridle sling can be used to lift the gate leaf in the normal position. Lugs should be located on the vertical truss panel points if possible.

(3) Gate stops. Timber bumpers should be provided to prevent damage to the gate leaf caused by the leaf being forced against the wall of the recess. Under normal conditions three bumpers are used for each leaf, with the top bumper placed below the operating rack or cables and the middle and lower bumpers placed on the center line of the respective horizontal trusses or frames. The bumpers should be made of 6- by 10-in.-white oak timbers approximately 2 ft 0 in. long, with each bumper attached to the vertical beam adjacent to the skin plate with four corrosion-resisting bolts. Each timber on the leaf has a companion bumper attached to the wall of the recess, with each pair of bumpers having matching alignment. The recess bumper is also attached with a minimum of four corrosion-resisting bolts, extending approximately 1 ft 4 in. into the concrete with an additional 3-in. standard hook. The bolts should be so spaced that the bolts in the timber on the leaf are not in line with the bolts in the timber recess. All bolts should be recessed to provide a minimum of 1 in. between the head of the bolt and the face of the timber. (See Plate B-36 for a typical detail.)

i. Embedded metals. The items normally included in this category are hinge anchorage, pintle base and

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anchorage, seal beam for the bottom seal, and the embedded plate which supports the side seal beam. The hinge anchorage and pintle base and anchorage have been discussed in previous paragraphs.

(1) The seal beam for the bottom seal normally is made up of a rolled beam with a corrosion-resisting plate attached to the top flange. The top of the corrosion-resisting plate is flush with the floor of the lock. The beam should be placed in second-pour concrete with anchor bolts, also used for adjustment, extending into first-pour concrete.

(2) The embedded plate which supports the side seal beam is located at the corner of the gate recess. This plate should be made of structural steel and should be anchored with bolts set in the first-pour concrete. The side seal beam should be bolted to the embedded plate with corrosion-resisting bolts. The seal contact of the beam should be clad with corrosion-resisting material. See Plate B-36 for typical details of side seal and bottom seal embedded metal.

j. Cathodic protection. Primarily two basic types of cathodic protection systems are used on sector gates. One system, using sacrificial anodes, is the least efficient of the two systems but has a lower initial installation cost. Another disadvantage of the sacrificial anode system is that the gate leaf has to be removed or dewatered for maintenance or replacement of anodes. Impressed current cathodic protection should be used on sector gates. See Chapter 7 for additional information on cathodic protection.

(1) The other system, commonly known as the impressed current system, has a higher initial installation cost but is more efficient than sacrificial anodes. Button-type anodes used with this system have the same disadvantages as the sacrificial anodes for maintenance and replacement.

(2) The thickness of the skin plate should be increased 1/16 in. and cathodic protection omitted from the convex face of the skin plate. This allows a better side seal as the seal can be placed closer to the skin plate of the leaf.

(3) Where possible to schedule the gates for removal or dewatering for maintenance and painting (at intervals not to exceed six years), sacrificial anodes should normally be used in lieu of the impressed current system unless more severe corrosive elements indicate the need for a more efficient system. When time intervals between

dewatering exceed six years impressed current should be used.

(4) Where the corrosive elements of the water require a more efficient system of cathodic protection the impressed current system may be used, utilizing string-type anodes that can be removed or replaced without dewatering or removing the gate.

(5) See Chapter 7 for additional information on cathodic protection.

k. *Erection and testing.* The same general procedures that were discussed for horizontally and vertically framed gates should apply to sector gates. Each gate leaf should have the same shop assembly and matchmarking as well as the same general allowable tolerances.

(1) The gate leaves should be erected in position on the pintle and temporary supports the same as horizontally and vertically framed gates. The clearances of the gate leaves above the lock floor may preclude the use of temporary concrete pedestals for erection.

(2) All items covered under miter gates herein should apply to sector gates with the exception of diagonals and zinc or epoxy filler. The remaining comments on erection, trial operation, and workmanship should be applicable to sector gates as well as miter gates.

4-2. Operating Machinery

a. *General description.* The sector gate is generally operated by machinery similar to the electric-motor-driven miter gate machinery. The machinery used normally consists of a hydraulic motor or an electric motor, a herringbone gear speed reducer, a specially designed angle drive gear unit, an electrically operated brake, limit switches, and other accessories connected so as to drive a large radius rake which is bolted to the top upstream edge of the gate. A general arrangement is shown in Plate B-54. An alternate machine utilizing a cable and drum arrangement can be used to pull the gate in and out of the recess. This arrangement is shown in Plate B-55. The machinery components would be similar to the gear machine except that a drum and cable would be utilized in lieu of the pinion and rack.

b. *Design considerations and criteria.*

(1) General. Difficulty was experienced in the design of the first sector gates when operating under reverse heads. Prototype tests showed that the

hydrodynamic and friction forces were much greater than anticipated in the design. The normal operating forces on sector gates are primarily caused by friction on trunnion and hinge pin, forces on seal bracket, bottom friction, and hydraulic loads. Extensive tests have been made to obtain operating forces on sector gates. These tests, made by the Waterways Experiment Station (WES), have been published in Technical Report H-70-2 and Appendix A to the report (USAEWES 1970, 1971). Subsequent tests made by WES resulted in the design of a new improved gate with operating forces approximately 20 percent of those experienced in the original designs.

(2) Machinery components. Under normal heads, sector gate tests have shown that the loads created by flowing water tended to close the gate but were considerably less than those observed under reverse heads. Under all reverse head conditions, loads imposed on the gate by the flowing water tended to close the gate. Loads increased with gate openings up to 5 to 7 ft then showed a tendency for a slow decrease at greater openings. Model data for gate openings of about 6 ft can be used to predict peak torque for various lower pools and reverse heads. Model and prototype tests demonstrated that the major loads on the gate are caused by structural members in the immediate vicinity of the skin plate at the miter noses of the gate leaves and by the side seal bracket that blocks side flow at the recess edge of the skin plate. Timber fenders, which are offset from the skin plate, have a very negligible effect on forces. General criteria applicable to machine components are presented in paragraph 1-11.

c. Determination of machinery loads. When determining operating loads for a sector gate, Technical Report H-70-2 and Appendix A to the report (USAEWES 1970, 1971) should be used as a guide. However, if a gate design varying considerably from the type shown in the report is used, model studies to determine the loads should be performed.

(1) After maximum operating conditions on the sector gates have been determined, the gate operating loads should be computed both for normal flow and for reverse flow conditions. Due to the construction of the bottom seal no bottom seal friction is created during reverse heads. Loads due to reverse head conditions will usually establish the size of machine to be used; however, loads due to normal heads should be checked.

(2) Water load on the gate will be created by the projected width of miter beam, skin plate rib, and seal bracket. Figure a, Plate 44 of Technical Report H-70-2, Appendix A, gives the peak closing pintle torque for the improved type gate. These torque curves are reproduced for this manual and are shown in Plate B-81. This torque is based on a gate having a total projected width of miter beam, skin plate rib, and seal bracket of 30.375 in. (17.875 in. + 8 in. + 4.5 in. = 30.375 in.). The torque taken from Plate B-82, Sheet 2, should be corrected in accordance with Froude's law of similarity to the lengths used on the proposed gate based on the scalar ratio. Hinge friction and pintle friction torque should be added to the above water load to determine the total machinery load. Reference should be made to Miscellaneous Paper H-71-4, paragraph 14 (USAEWES 1971), in conjunction with establishing reasonable values of hinge and pintle friction. Typical calculations for determining loads on the improved type of sector gate are shown in Plate B-82, Sheets 1-3.

d. Operating machinery controls. Sector gates are usually controlled from a small control house located adjacent to each pair of gate leaves. For electric motor drive, the control equipment consists of the combination of full voltage magnetic controllers, limit switches, control pushbuttons, and switches arranged to produce the desired operating sequence. For fluid motor drive, the speed of the gate is varied by controlling the flow of oil to the fluid motor either by throttling or by use of a variable stroke piston pump. With this system, control valves can be either manually or electrically controlled.

Chapter 5
Vertical-Lift Gates

5-1. Vertical-Lift Gates

a. General description.

(1) Two types of vertical-lift gates may be used. One type, a double-leaf or triple-leaf, vertical-lift gate, referred to in this chapter as emergency gate, is located at the upper end of each lock chamber. The upstream leaf, consisting of horizontal girders and a skin plate, is designed for use as a movable sill. The downstream leaf, also consisting of horizontal girders and a skin plate, is designed for operation through flowing water. The downstream side of both leaves is provided with a grating screen to prevent drift and debris from lodging between the horizontal girders. A screen and bulkhead are provided above the ends of each leaf to prevent drift from entering the recess and to prevent damage to the recess from tows entering the locks. The hoist component at each side of a gate is mounted on a structural steel frame which is anchored to a concrete structure on the lock wall, the unpowered component for each lock being on the middle wall and the powered component on the opposite wall. The structure is of such height that the hoist machinery will be above high water. The hoist assembly is enclosed in a concrete housing with removable aluminum roof sections. For the normal open or stored position, the leaves are lowered into the sill. The emergency gate is used for lock closure in the event of accident or damage to the lock gates that otherwise would result in a loss of the navigation pool. The gate will also be used to skim ice and drift from the lock approaches, or for upstream lock closure during maintenance and repair operations in the lock chamber, and in connection with opening the lock gates to pass flood flows when necessary after navigation is suspended. (See Plate B-42.)

(2) The other type of vertical-lift gate is a single-leaf gate that can be used at either end of a lock and is frequently used as a tide or hurricane gate along the sea coast. This type of gate is raised when not in use, permitting normal traffic to pass underneath. This type is referred to as a "Tide" or "Hurricane" gate in this chapter (See Plate B-41).

b. Skin plate.

(1) The primary design method for skin plates of vertical-lift gate leaves supported by girders or trusses should be as described previously in paragraph 2-1c for horizontally framed miter gates. The skin plate may be designed by the method of Column Analogy, utilizing the thickness of the flange in conjunction with the skin plate to form a beam of variable section spanning from center to center of girder webs. The stress should be determined at the center line of girder webs, which is the end of the assumed beam, at the edge of the girder flange, and at the center of the beam, midway between girder webs. See Plate B-43 for additional information on this method of analysis.

(2) The skin plate of gate leaves with close girder spacing or without intercostals may be designed as continuous members.

c. Framing.
Vertical-lift gates may be fabricated of plate girders or horizontal trusses, with economy normally indicating which system will be used. The basic framing of gates utilizing plate girders consists of the plate girders, downstream bracing, intercostals, diaphragms, and end girders. When horizontal trusses are used the main framing items are the horizontal trusses, vertical trusses acting as diaphragms, downstream bracing, and end girders. When gates are lifted above the locks for clearance, the lifting towers are included in the major framing.

(1) Plate girders. Plate girders are essentially the same as those for horizontally framed miter gates. Girder webs should be determined in accordance with current AISC Specifications, with the web depth-to-thickness ratio such that no reduction in the allowable stress for the compression flange is necessary. In the event longitudinal stiffeners are considered to be advantageous on girder webs for special conditions, the stiffeners should be placed and sized according to the American Association of State Highway and Transportation Officials Specifications.

(a) The girders should be designed by the moment of inertia method. The effective design length should be the full length from bearing. For buckling about the minor axis of the girder due to any applicable axial loads, the effective length may be the lesser of diaphragm spacing or panel spacing of vertical trusses formed by the downstream bracing.

(b) Girders should be designed to withstand water load and a combination of water and dead load and boat impact. Emergency loadings such as boat impact shall have a permissible increase of one-third in the allowable stresses. The water load should include wave pressure if

applicable, with consideration given to the effects of breaking or nonbreaking waves, whichever is more appropriate. The downstream flanges of girders that act as the chord member of a vertical truss formed by the downstream bracing shall be designed for the combined loading of water and dead load. The force in the flange, from acting as the chord member of the vertical truss, should be determined from one-half the vertical load on the leaf, assuming the skin plate to carry the remaining one-half. The resulting axial force in the flange shall be considered as an eccentric column, with the stress being the normal P/A + MC/I. The allowable axial stress F_a shall be determined by using a value of the radius of gyration computed as shown in Plate B-43. The allowable bending F_y shall be the appropriate value as determined from EM 1110-2-2105 or from AISC as indicated in paragraph 1-6b.

(c) Girder webs should be investigated for shear and the requirement for transverse stiffeners as well as the effect of combined shear and tension, which may reduce the allowable tensile stress to less than $0.6F_y$. Web crippling should also be investigated for all uniform and concentrated forces applied to the girders.

(d) Deflection should be investigated for all girders, especially those of high strength steel.

(2) Horizontal trusses. Horizontal trusses serve the same function as plate girders, with the choice of plate girders or trusses being determined by economics and weight. Where trusses are used the diagonal members should be designed as tension members. Working lines of truss members should coincide with the centroidal axis of the members in order to minimize secondary stresses. Secondary stresses in truss members caused by stiffness, restrained joints, and excessive deflection due to truss depth limitation should also be investigated. Where beams are used as chord members the webs are normally placed horizontally, except the top frame where it may be more advantageous to place the webs vertically to support walkways and equipment. An operational loading equivalent to a minimum differential head of 6 ft applied to either side of the gate should be considered as acting on each truss. The reduction of negative moments for continuous members in the truss is not recommended. Deflection should be investigated for all horizontal trusses.

(3) Diaphragms. Diaphragms on vertical-lift gates where plate girders are utilized serve two main purposes, one being to distribute girder loads and the other to support the vertical loads applied to the leaf where the leaf

is being used as a movable sill. The diaphragm should be sized according to AISC Specifications governing the width-to-thickness ratio of the vertical web. Vertical stiffeners should be utilized in accordance with the appropriate sections of AISC Specifications, with the stiffeners and effective section of the web being designed as a column, with each pair of stiffeners carrying a proportional part of the total vertical load on the diaphragm.

(a) The design shear load applied to the diaphragm will be the difference between the assumed load to cause equal deflection of the girders and the actual water load on each girder. The diaphragm should be checked for this shear and the requirement for transverse stiffeners to prevent buckling of the diaphragm due to this shear load. The vertical flange of the diaphragm should be designed as a column, consisting of the flange plate and the effective section of the diaphragm. The effective or unsupported width of flange and the effective section of the diaphragm should be determined according to the AISC Specifications. The load applied to the flange is the appropriate load from the vertical truss action of the downstream bracing.

(b) The extension of the diaphragm on the bottom of the gate leaf should have a bearing plate designed to resist both bearing and moment, with the forces created from the reaction between the plate and the concrete or steel pedestal. Stiffeners should also be provided on the extension of the diaphragm, acting as columns to transfer the load from the diaphragm through the bearing plate to the support pedestal.

(4) Vertical trusses. Vertical trusses, used in gates utilizing horizontal trusses instead of plate girders, perform the same function as the plate diaphragms discussed in the preceding paragraph. The vertical chord members should be designed as columns with the effective length equal to the horizontal truss spacing. The degree of fixity at the ends of the vertical chords, connecting them to the horizontal trusses, will determine the appropriate effective length factor K for design of the members as columns, with a minimum value of 0.65 being used for members considered completely fixed. The effect of the vertical chord acting as a chord of the downstream bracing should also be included in the design of the vertical truss. The deflection of the vertical trusses should be investigated, giving consideration to the effects of the deflection of horizontal trusses on the vertical trusses.

(5) Downstream bracing. The downstream bracing of a gate leaf, in conjunction with the appropriate girders or trusses, forms a vertical truss that supports the vertical

forces applied to the leaf, including the weight of the leaf. Normally the bracing carries one-half of the vertical load with the skin plate carrying the remaining one-half. The bracing should be placed so that the maximum number of members, while acting as truss members, will be designed for tension rather than compression. End connections of the bracing should be such that the forces in the member will be applied concentrically as far as practical. Any eccentricity of the connection from the gravity axis of the member should be considered in determining the stress in the member. The stress created in the girder or horizontal truss by the downstream bracing shall be combined with the bending from horizontal forces as indicated in preceding paragraphs on plate girders.

(6) Intercostals. Intercostals are essentially the same as discussed in the section on horizontally framed miter gates. The span of the intercostal is from center to center of horizontal girders or trusses, with the loading beginning at the edge of the flange or 6 in. from the center line of the girder web, whichever is the smaller dimension. The skin plate is assumed to be an effective part of the intercostal, with the effective width determined according to AISC Specifications. The most desirable shape for intercostals is an unequal leg angle, with the longer leg of the angle attached to the skin plate. This gives a much stronger member than a flat bar used as an intercostal. For additional information, see paragraph 2-1c(2).

(7) End girders. End girders, on vertical-lift gates used as upper gates where the gate is lowered into the sill or used as a movable sill, serve to distribute the vertical and horizontal reactions of the gate or gate leaf. These girders are designed as columns with a combined axial and bending load. The axial load is a combination of the dead weight of the gate in the dry plus silt and mud load. This force, normally applied through offset brackets attached to the outside of the end girder web, produces a bending moment in the end girder as well as a normal direct axial load. Usually the force on the end girder is divided between two brackets, with each bracket, along with its effective web and flanges, considered as an individual member, acting as a continuous beam fixed at the horizontal girder webs. Each member is subjected to a combination of bending and axial loading.

(a) The bracket on the outside edge of the end girder web, shown as bracket A in Plate B-44, makes up a vertical member in conjunction with the vertical plate that acts as a flange of the end girder, and the related flanges of the bracket itself.

(b) The bracket shown as bracket B in Plate B-44 makes up a vertical member consisting of the bracket and usually two standard rolled tees attached to the end girder web above the tapered segment of the bracket, forming a member with a haunched section on one end.

(c) The brackets are checked for shear in two directions, one being the vertical shear from direct loading and the other being horizontal shear caused by the moment resulting from the beam action of the member. See Plate B-44 for information on a typical effective column (or beam). Welds attaching the bracket to the web of the end girder are subjected to both direct shear and bending stress and should be sized accordingly.

(d) The end bracket is fitted with a base plate designed for bearing and bending. Where the loads are of such magnitude that the base plates would be excessively thick to prevent bending, stiffeners may be used to support the plate and thereby keep the thickness of the plate in a more desirable range. The stiffeners should be attached to the bracket web plate and be of sufficient length to transfer a proportional share of the force from the web to the base plate, acting as a short column.

(e) The lifting pin plates are generally attached to the end girder web where reaction wheels are not used. The transfer of the vertical force should be made through the welds attaching the pin plates to the end girder web. When reaction wheels are used the lifting connection is generally outside the end girder or reaction girder web. The vertical plate serving as the downstream flanges of the horizontal girders is extended past the reaction girder web and, with the appropriate stiffeners, serves as the vertical web for the lifting connection. The entire end of the gate is usually extended and boxed in by the extended vertical plate, skin plate, and an end plate attached to the ends of the horizontal girder webs.

(f) End girders on vertical lift gates used as lower gates, or where the gate is lifted above the sill for clearance, usually serve only to distribute the horizontal force applied to the gate, acting similar to the vertical plate diaphragm discussed in paragraph 5-1c(3), distributing the load so that all reaction wheels carry their appropriate part of the total force applied to the gate. The end girder for this type of gate consists of a solid end plate with an upstream and a downstream flange. The flanges may be of rolled members or of flat plate. The vertical load of

the gate is transmitted through the vertical diaphragm or trusses through the bottom seal assemblies to the concrete sill.

(8) Towers. Where vertical-lift gates are used for the lower gate of locks, or where gates must be lifted above the sill for clearance, towers are usually required on top of the lock walls to lift the gate to the required vertical clearance. The towers should be designed for the vertical load of the gate, including 50 percent impact, applicable vertical bridge load, loading due to expansion or contraction of bridge, plus the wind load applied to the gate, bridge, and tower. Wind forces should be as indicated by TM 5-809-1, with a minimum force of 25 psf applied for all areas. The allowable stress can be increased by one-third for all loading conditions that include wind load, provided that the required section computed on this basis is not less than that required for the design dead load, live load, and impact, computed without the one-third stress increase. Consideration should be given to the effect of torsion on the tower, created by the wind load, reaction from the gate, and eccentric loading, as well as wind on the tower itself.

(a) Two basic types of towers used are steel framed or reinforced concrete, with economics normally determining the appropriate type. Hybrid towers of composite construction may in some cases be advantageous but normally are not the most economical. Steel towers should be designed on the basis of each face acting as a planar truss, with the diagonal members carrying tensile forces only. Horizontal cross-bracing should be provided at each panel point to resist shearing and torsional forces caused by the eccentricity of loading along the guide system as well as wind on the tower itself. Concrete towers should be designed with a minimum of 3,000-psi concrete, with the loading essentially the same as that for steel framed towers. Both types of towers should be designed as free-standing cantilevers, with the baseplates for steel towers attached to mass concrete with corrosion-resisting anchor bolts. Baseplates should be checked for bearing and bending from downward axial loads and also for bending due to uplift, with the connection of the baseplate to the tower leg being analyzed for maximum stress. For concrete towers the applied torque should be considered as resisted by pure flexure in the flanges at the cantilever fixed end and by pure torsional shear above the fixed end, with a transitional section between the two. The critical stress may be located in the transition with the shape of the tower influencing the length of transition and the stress concentrations.

(b) The gate guide system should be connected to steel framed towers only at panel points, so that gate wheel reactions will cause no lateral bending in tower legs. In the event it is not practical to avoid bending in some tower members these members shall be designed for the combined axial and bending loads. The guides should be designed as continuous members subject to moving loads from the gate reaction wheels. Where the guide system is attached to concrete towers, consideration should be given to the transfer of shear between the steel portion of the guide system and the tower proper, ensuring that suitable means of transfer are provided.

(c) If a bridge is used on top of the towers to support the vertical load of the gate, the bridge should be designed for the dead load plus impact and wind. The bridge should be connected to the top of the towers with fixed bearings, pinned to allow for deflection of the bridge and towers. The bearings should be designed in accordance with AASHTO Specifications, with the bridge framing meeting the requirements of EM 1110-2-2105 or AISC as indicated in paragraph 1-6b. Bracing shall be provided between girders to stabilize the bridge against lateral loads.

(d) When a bridge is not used, cantilevered gate supports must be used on top of the towers. This system causes more tower deflection under load and this should be considered when selecting the support system for the gate.

(e) Whichever support system is selected, cantilevered supports or a bridge, the tower deflection must be checked and the effect considered on the guide system of the gate. If necessary the towers may be cambered so that the gate guides and tower faces at channel-side will be in vertical alignment under the dead load of the gate.

(f) Access across the lock should be provided by way of the towers and the bridge as well as the normal walkway across the top of the gate.

(g) Consideration may be given to the use of counterweights to reduce the cost of electrical and mechanical equipment but the disadvantages of the counterweights, such as the additional load on the tower, the possibility of the need for the full weight of the gate to seat the gate, and the special adaptation of the tower wind bracing to provide clearance for the counterweights and their guide systems, must be compared with the advantages before a final decision can be reached.

d. End bearing. The end bearing of vertical-lift gates is essentially the same as that for a simple beam. There the upper gate is made of two leaves, the upstream leaf, depending on the intended use of the leaf, may be fitted with standard bearing plates designed for moment and bearing. The bearing surface of the plate should be made on a radius to act as a rocker to allow for deflection of the gate leaf. For the allowable stresses and dimensions related to the radius of the curved bearing the current AASHTO Specifications should be used. Where reaction wheels are used so that the gate may be operated under load, the wheels may be sized so that the requirements of AASHTO are met or other similar methods of analysis may be used. For additional information concerning reaction wheels see paragraph 5-2*b*(3)(f).

e. Seals. Rubber "J" seals are used to seal between the end of a single-leaf gate, or the downstream leaf of a divided gate, and the gate recess. Where the upper leaf is used as a temporary sill a rubber "J" seal is bolted to the upstream face of the leaf to provide a seal between the leaf and the existing concrete sill. A short section of rubber caisson seal is used to seal between the gate and the recess on the bearing-bar side of the leaf. One method of sealing between the two leaves at the lower edge of the skin plate of the downstream leaf is to use a tube member normally made of aluminum and in interchangeable lengths, held on top of the upstream leaf by guide brackets and forced into position against the skin plate of the downstream leaf by the force of the water. The seal tube is fabricated so that the water fills the tube after installation, with the tube and brackets installed in the dry and the upstream leaf lowered to a point where the tube is filled before lowering the leaf into its final position. The effect of the water load on the tube should be investigated.

(1) Where the gate is made of a single leaf, a solid block-type rubber seal is used on the bottom of the leaf, sealing against embedded metal in the floor of the lock.

(2) All seals should be fastened with corrosion-resisting bolts spaced approximately 6 in. on center. For additional information on seals, see Plates B-40 and B-41.

(3) Where corrosive elements are encountered, consideration should be given to using corrosion-resisting seal plates or the use of a plate or member with the exposed surface clad with corrosion-resisting metal.

f. Lifting arrangement. Vertical-lift gates are usually lifted by an arrangement of sheaves and cables. Where gates are used as upper gates, the hoist motor is normally fixed on the lock wall and through an assembly of sheaves attached to the gate, lifts the gate to the required heights.

(1) Similar systems are used for lower gates except that the hoist motor may be mounted on the gate or if a bridge is used between towers, the hoist motor is generally mounted on the bridge.

(2) For any system the supporting members used on the gate or for supporting the hoist drums or sheaves shall be designed for the actual load plus 100 percent impact. This should apply to all related pins, bolts, and anchor bolts.

g. Dogging arrangement. Support beams may be used for vertical-lift gates used as upper gates or where the gate is not lifted above the lock walls. These beams should be designed for shear and moment, using 50 percent impact for the applied loading. Stiffener plates should be used on each side of the support beam web under the support brackets of the gate and at the reaction points of the support beam.

(1) Where the gate is lifted above the lock wall on towers, dogging devices should be provided to allow the tension to be removed from the lifting cables under continuous loading. The preferred dogging device consists of a horizontal pin that moves into pin plates attached to the top of the gate. The pin should be so arranged that it can be operated from the control station of the gate, with instruments provided to show when the pin is fully engaged or fully released. (See Plate B-43 for suggested details.)

(2) The pin and pin plates on both the gate and support structure should be designed for the full gate load plus 100 percent impact.

(3) Limit switches should be installed so that when the cables become slack the gate drive motor stops and the brakes set. (See paragraph 5-2*d* for additional information.)

h. Tracks. Tracks for vertical-lift gates are usually incorporated into the guide system, with the track itself consisting of a corrosion-resisting plate where contact with salt or brackish water is a possibility. Where the corrosive elements of the water are minor, as with normal fresh water, the bearing plate or track may be of structural steel with a cladding of corrosion-resisting material on the exposed surface.

(1) Above the water line, consideration may be given to the use of structural carbon steel for the bearing or track plates with the determining factor being the economic comparison of maintenance and replacement against the higher cost of clad material.

(2) The bearing plate or track should be attached to a suitable support member, normally a standard rolled beam, with the support member embedded and anchored in the concrete wall or attached to the tower at tower panel points.

(3) The track plates are provided in pairs, one each on the upstream and downstream side of the recess or guide system.

i. Guides. The guide system for a vertical-lift gate consists of two bearing or track plates and an end guide plate. The bearing plates are so arranged that the wheels or bearing plates of the gate react against the bearing plates of the guide system. The system is arranged so that the gate may be loaded from either side and the bearing plates will remain effective.

(1) The end bearing plates are similar to the reaction bearing plates but are placed so that bumpers on the end of the gate will strike the end bearing plate and prevent excessive lateral movement of the gate in relation to the lock.

(2) The normal clearances should allow for not more than 1 in. total movement between gate and bearing plate and not more than 1/2 in. between gate and end bearing plate. See Plate B-41 for suggested details of a guide showing the recommended clearances.

(3) The end guide or bearing plate should be of the same material as the bearing or track plates, using the same criteria to determine the use of corrosion-resisting steel, clad steel, or standard structural steel.

(4) To minimize the effects of the guide system on the support towers the system should be connected to steel towers only at panel points of the structure.

j. Sill. The concrete sill for a vertical-lift gate may be of two types. One type, where the gate is lowered into a recess behind the sill, carries the weight of the gate on the lower segment of the sill on extended concrete pedestals or on steel pedestals bearing on an extension of the sill. The other type of sill, where the gate is lifted above the sill for clearance, carries the full weight of the gate on the top of the sill, with the weight of the gate being transferred through the seal assembly along the entire length of the gate. For this type of sill an embedded beam with corrosion-resisting seal plate attached is used in the top of the sill. The beam should be placed in second-pour concrete with anchor bolts, also used for adjustment, placed in first-pour concrete. The top of the corrosion-resisting seal plate should be flush with the concrete of the sill.

k. Walkway. Where gates are lifted above the sill for clearance and the top of the gate in the lowered position is at the same elevation as the lock wall, access across the lock should be provided by means of a walkway on top of the gate. The walkway should normally be the same overall width as the gate, with the walkway maintaining its width over the tapered ends of the gate. The minimum width of walkway shall be 4 ft 0 in. back-to-back of support angles. Where the gate width is more than 4 ft, the walkway may be made the minimum width if the additional width is not needed for the transfer of equipment. The support angles will also act as toe boards for the walkway, with a minimum vertical leg of 3-1/2 in. by 3/8 in. The vertical supports of the walkway should be designed as columns and located on the diaphragms and vertical members of the gate where practical.

(1) The walkway shall be designed for 100 psf with grating having a minimum depth of 1-1/4 in. The ends of all grating shall be banded with bars the same size as the bearing bars, with panels made in convenient size for installation and removal. Usually four standard clips per panel will be used to fasten each panel of grating. Grating shall normally be type II and hot-dipped galvanized after fabrication.

(2) Handrail should be made with 2-in. diameter extra strong pipe post and 2-in. standard pipe rail, or equivalent aluminum rail and post if economy dictates aluminum railing for the lock walls. Railing should be made removable and in convenient size panels for installation and removal. When standard and extra strong pipe is used handrail panels should be hot-dipped galvanized after fabrication. See paragraph 2-1*n*(5) for additional information.

l. Erection and testing.

(1) The procedures for vertical-lift gates are essentially the same as those for "miter gates." Items that do not apply to vertical-lift gates are diagonals, pintle, anchorage links, and zinc or epoxy filler. The remaining discussion pertaining to trial operation, testing, and

workmanship should, in general, apply to vertical-lift gates. (See Chapter 2.)

(2) Towers for vertical-lift gates should be checked for deflection during the trial operations of the gate to determine if the guide system is in vertical alignment. The vertical alignment should be such that the guide and bearing plates of the guide system remain fully effective without binding on the gate and without excessive deflection or distortion of any member.

5-2. Operating Machinery

a. General description. Two types of vertical-lift gates may be used. One type is a double-leaf gate that normally is lowered into the sill. One leaf is located upstream from the other, and may be used as an upper lock gate or as an emergency gate in conjunction with a normal miter gate. This type of gate is referred to herein as an "Emergency Gate." The other type of vertical-lift gate, a single-leaf gate, can be used at either end of a lock and is frequently used as a tide or hurricane gate along the sea coast. This type of gate is raised when not in use, permitting normal water traffic to pass underneath. This type of gate is referred to herein as a "Tide" or "Hurricane" gate. On both types of gates, the leaves are raised by a cable hoist with the machinery mounted on the lock walls.

(1) Emergency gate machinery. The emergency-type gates generally consist of two leaves, one upstream and one just downstream of the other. The downstream gate is equipped with wheels and is designed to be raised in flowing water. The upstream gate is designed to be raised only in a balanced pool or when the swell head is 1 ft or less. The gates are used when failure of the lock miter gate occurs or when it is necessary to pass ice or debris with the miter gates open and latched in the recess. When operating the gates, the upstream leaf must be raised in steps behind the downstream leaf. Operating procedures for this type of gate are shown in Plate B-39.

(a) The hoist machinery used to raise the emergency gates consists of a double grooved rope drum driven by two stages of open spur gearing, a herringbone or helical gear reducer, and an electric-drive motor with spring set, magnet release holding brake. The rope drum has several layers of rope. One rope from the double drum attaches to one end of the gate through a multipart reeving. The other rope from the drum crosses the lock through a tunnel in the gate sill and passes through a multipart reeving which is attached to the other end of the gate. (See Plates B-56 and B-57.)

(b) The hoist components are generally mounted on a structural steel frame which is anchored in various ways to the lock wall or a concrete structure. Each leaf is raised by its individual hoist mounted side by side on the lock wall. The hoist structure is of such height that the machinery will be above high water. A typical hoist arrangement is shown in Plate B-58.

(2) Tide gate or hurricane gate machinery. The machine used for raising this type of gate consists of a dual drum cable hoist mounted adjacent to one of the lifting towers. The two drums are driven by a pinion gear located between the two drums. A triple reduction enclosed gear unit drives the pinion. The gear unit is driven by a two-speed electric motor with a double ended shaft. A magnet-type electric brake is provided between the motor and reducer. The motor shaft extension permits the connection of a hydraulic "emergency" lowering mechanism. The low speed of the motor is used when starting and stopping the gate. The gate is normally lowered by means of the electric motor; however, in the event of a power failure, the gate may be lowered by means of the hydraulic mechanism.

(a) The emergency lowering mechanism consists of a radial piston-type hydraulic pump connected to the electric motor shaft extension, a flow control valve, oil cooler, check valve, and necessary piping, all connected and mounted on an oil storage reservoir. When lowering without electric power, the weight of the gate, acting through cables and reduction gearing, turns the hydraulic pump. Oil from the pump is circulated through a flow control valve creating a transfer of energy to the oil in the form of heat. Excess heat in the oil is removed by a tubular-type oil cooler.

(b) The two drums wind both ends of a continuous cable which lifts the gate through a series of sheaves, the number of which are selected to give the mechanical advantage desired. Two of the sheaves mounted on the gate serve as equalizing sheaves to equalize the line pull in event one drum winds slightly more cable than the other. Each drum is precision grooved so that each winds the same amount of cable on each layer. Where the fleet angles of the cable approaching the drum exceed 1.5 deg, a fleet angle compensator must be provided.

(c) The hoist machine should be located adjacent to the gate and in line with the hoisting sheaves. The hoist should be enclosed in a small protective building. A hydraulically operated dogging device should be provided to secure the gate in the raised position. A typical hoist arrangement is shown in Plate B-59.

b. Design considerations and criteria.

(1) Emergency gate machinery. The design of vertical-lift gate machinery should be determined by the combination of all loads applicable to the type and design of gate used. For two-leaf emergency gates, the upstream leaf or movable sill should be raised only under balanced head conditions or when lower pool is no more than 1 ft below the upper pool (the swell head when control of the river is lost). For design purposes a "swell head" of 1 ft should be used. Since horizontal force on this gate is light, gate rollers may not be required and the gate should be designed to slide against friction plates in the gate recesses.

(a) The downstream leaf will normally be raised in flowing water, thereby creating an additional horizontal and vertical force. The horizontal force usually will be great enough to require the use of reaction rollers on each end of the gate. Gate lifting speed for both leaves should be approximately 1 ft/min to 5 ft/min adjusted to suit the speed of the nearest standard speed motor.

(b) When this type of gate is used as an operating lock gate it would normally be operated under balanced head conditions and not through flowing water. Gate speed should be approximately 5 ft/min to 10 ft/min.

(2) Tide gate machinery. Criteria for the design of tide gate machinery are the same as those for the emergency gate machinery except that the gate must be capable of being raised or lowered against a differential head, plus against a force created by wind on the exposed section of the gate. In order to clear traffic passing under the gate, the gate must be raised a greater distance than either of the emergency-type gate leaves; therefore, the lifting speed should be approximately 5 ft/min to 10 ft/min or a speed sufficient to permit opening the gate in approximately 10 min. Wind load on the exposed section of the gate should be assumed to be 20 psf (for machinery design). (See Plate B-59.)

(3) Machinery components.

(a) General criteria. General criteria applicable to all types of operating machinery covered in this manual are presented in paragraph 1-11.

(b) Hoist motor selection. The required torque of the downstream vertical-lift gate hoist motor should be the root mean square value of torque vs. time curve for operation of the gate with the motor selected having a 1.15 service factor. The peak torque required should not exceed 125 percent of the rated full load motor torque. The normal hoist load for the downstream leaf will be the loads resulting from the required torque of the motor. The hoist motor should have torque characteristics conforming to Guide Specification CW-14615. A desirable feature to be considered is variable speed (AC or DC) hoist motors with a ramping function adjustable through the drive controllers.

(c) Hoist load division. The normal hoist load shall be considered as equally divided between the two drives of the hoist. For nonequalizing hoist arrangements, the loads resulting from the maximum torque of the motor will be divided between the two drives of the hoist by assuming that only one side of the gate is jammed. The load on the jammed side will be the loading resulting from the maximum torque of the motor minus the loads taken by the free side. Both drives of the hoist will be designed to withstand the jammed loads. For equalizing hoist arrangements the stalled torque of the motor will be considered as equally divided between the two drives of the hoist. For emergency-type gate machinery, force control switches may be used to limit the rope pull under stalled conditions and thus reduce the loads on the machinery components.

(d) Wire rope. Wire rope for these types of hoists should be 6 × 37, preformed, lang lay, independent wire rope core, 18-8 chrome-nickel corrosion-resisting steel. Wire rope shall be designed for a factor of safety of 5 based on normal load. A factor of safety of 3 should be provided for peak loads occurring during normal operation and a minimum factor of safety of 1.5 based on the maximum stalled rope load. Where multilayer hoist drum-winding is necessary, 6 × 30 Type G, lang lay, independent wire rope core, flattened strand wire rope should be used.

(e) Sheaves. Sheaves should be aluminum bronze bushed or antifriction bearing type as dictated by the conditions involved. Sheaves should be of standard dimensions with grooves clad with stainless steel. Published ratings of sheaves should be used in determining the factor of safety. The diameter of the sheaves may be as small as 24 times the rope diameter when used with 6 × 37 strand wire rope for an emergency-type gate. When used with a lock operating gate, sheave diameter should be 30 times the rope diameter.

(f) Gate wheels. Wheels for the underwater gates are a critical item and should be designed for the individual conditions encountered. A gate being raised with a considerable horizontal load caused by flowing water

would have considerable deflection at ends. To avoid point contact of the wheels on the flat plate track caused by gate deflection, the wheels should be constructed with a crowned, hardened tread. A method for designing a wheel subject to gate deflection is shown in Plates B-90. This method was developed utilizing formulas from Roark and Young (1975). (The formulas in the fifth edition may also be used. However, the formulas for computing maximum compressive stress are in error.) Formulas give the maximum compressive stresses, which occur at the center of the surface of contact, but not the maximum shear stresses, which occur in the interiors of the compressed parts, nor the maximum tensile stress, which occurs at the boundary of the contact area and is normal thereto. Due to the flexure in the gate, it is difficult to determine accurately the distribution of load on the gate wheels; however, it is considered satisfactory to design the wheel tread for a maximum compressive stress of from 2.0 to 2.5 times the yield strength of the material involved based on the maximum wheel load from the gate. A slight misalignment of the track surfaces will prevent a wheel of the gate from bearing on the track for short distances of travel, causing an overload on some of the adjacent wheels. This condition should be taken into consideration when determining maximum wheel load. An option to the crowned wheel to compensate for gate deflection at the ends would be to use flat wheels with self-lubricating, self-aligning, spherical bushings. These are available in many bearing and lubricant combinations to suit a variety of applications. Self-lubricating, self-aligning, spherical bushings have been used successfully in nuclear offshore, industrial, structural, and dam applications.

(g) Hydraulic lowering brake. A vertical tide gate is normally lowered by an electric-drive motor on the hoist, with a diesel electric generator set standing by in the event of power failure. In some cases, it may be desirable to use a second standby means of lowering the gate. This can be done by coupling a hydraulic motor to the shaft extension of the electric-drive motor. This fluid motor is connected in an oil circuit which permits free flow of the oil in the raise position but restricts flow in the lowering position. A typical circuit required for this operation is shown in Figure 5-1. The flow control valve used in this circuit should be designed and adjusted in the field to limit the speed of the electric motor to about 140 percent of its synchronous speed in order not to damage its windings or rotor. The flow control valve and fluid motor shall be sized so that the pressure of the oil leaving the motor shall not exceed the normal working pressure rating of the fluid motor. When lowering the gate, approximately 10 min may be required and

during this time braking energy will be transformed into heat in the oil as it passes through the flow control valve. A shell-and-tube-type heat exchanger must be provided in the circuit to prevent the temperature of the oil in the tank from exceeding 120 deg F. Since this system is used so seldom, cool clean potable water or raw water may be used in the heat exchanger then exhausted to drain. A thermostatically controlled valve may be used to automatically control the flow of water through the heat exchanger.

c. Determination of machinery loads.

(1) Since this type of gate is required to be closed in flowing water, considerable difficulty was originally encountered in the design of the crest for the downstream leaf. The original gate, in laboratory tests, was found to bounce violently during certain tailwater conditions. In order to obtain a gate which would perform satisfactorily, WES was requested to perform a series of tests on gate crests for this type of gate. Eight alternate gate designs were investigated, incorporating the following modifications: triangular-shaped crest with slope on downstream side; crests with the apex offset from upstream gate face by a horizontal or sloped surface; vented girders; crest skin plate; various girder locations; truss-type gates; and combinations of the preceding modifications.

(2) The design recommended for prototype construction is a triangular-crest with a IV on 3H sloping upstream offset and has the flanges of the gate girders turned downward. This design was found stable for all conditions investigated and required no aeration of the crest. Maximum downpull on the gate was about 220,000 lb and maximum uplift was about 50,000 lb. A curve showing uplift or downpull plotted against gate position above sill is shown in Plate B-89, Sheet 10. Loads taken from these curves should be used in the design of vertical-lift gate machinery where the gate is of similar proportions. The complete results of the above tests may be found in Report 2-527 (USAEWES 1959).

(3) In designing the downstream leaf of a vertical-lift emergency gate hoist, the following loads should be considered and used to determine cable pull.

(a) The weight of the gate leaf, trash screens, and recess protection in air. There should be no buoyant effect since the normal tailwater is generally too low to keep the gate submerged when it is lifted a few feet.
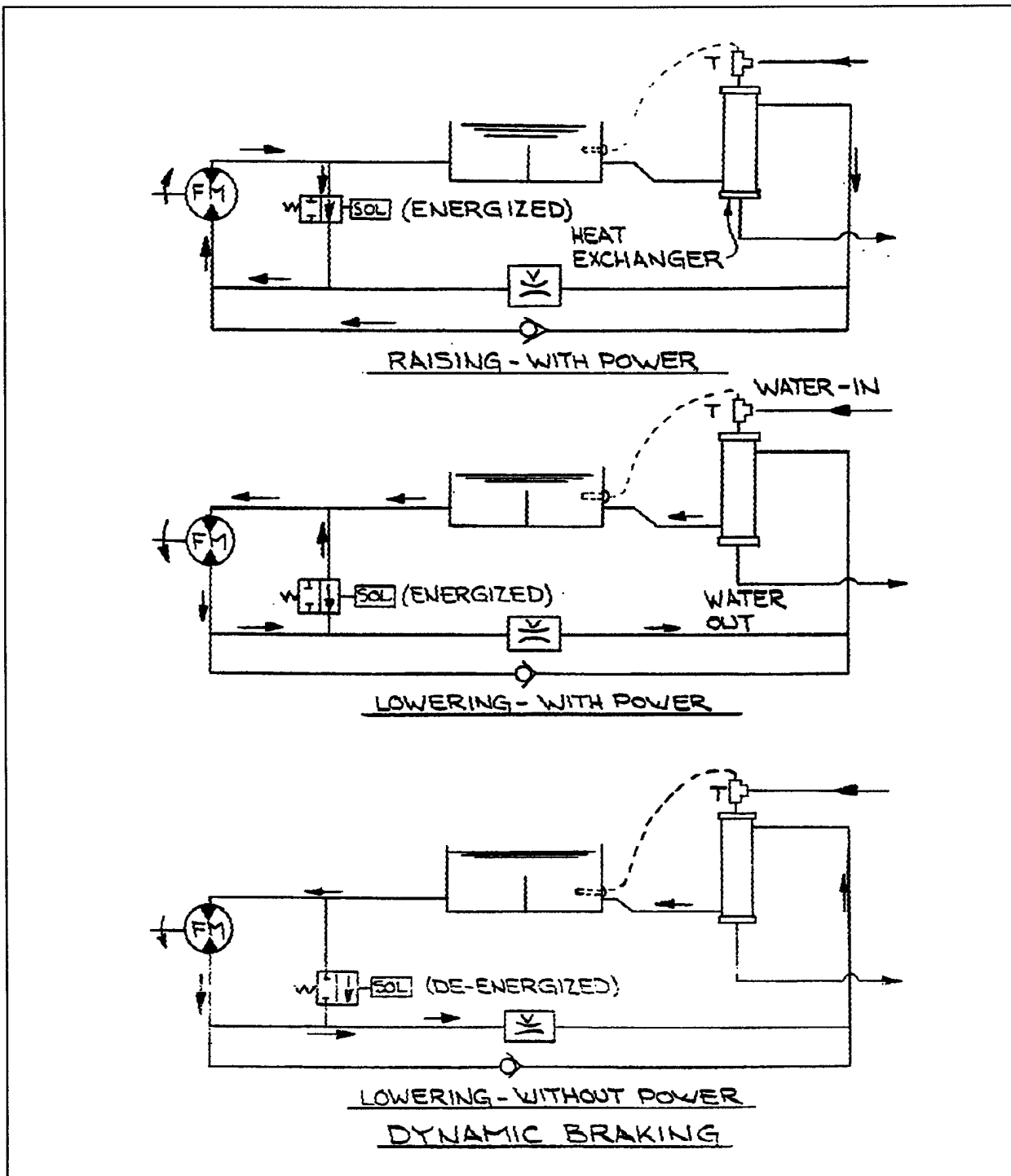
Figure 5-1. Typical circuit requirements for raising and lowering a vertical tide gate

(b) Silt at 125 pounds per cubic foot (pcf) which may be trapped above the web of the girders to the height of the downstream flange.

(c) Side seal friction. Load caused by sliding friction using coefficient of rubber on steel of 1.0.

(d) Roller friction. The total friction due to the gate reaction rollers running against steel tracks and the friction of the bearings in the reaction rollers shall be taken as 5 percent of the load normal to the gate leaf.

(e) Downward hydrodynamic force. This force on the gate nappe when the gate is raised through flowing water may be obtained from the curve showing results of studies by WES. (See curve in Plate B-89, Sheet 10.)

(4) The upstream leaf normally will not be equipped with reaction rollers or buoyancy tanks. It should be lifted only under balanced head conditions or when lower pool is 1 ft or less below upper pool (the swell head when control of the river is lost). The hoist design load will be the dead weight of the gate leaf in air, side seal preset force, weight of trash screens, weight of silt load (when raised to maintenance position), or the summation of the following, whichever is larger:

(a) Weight of gate leaf minus weight of water displaced.

(b) Silt load amount trapped by flanges less weight of water displaced.

(c) Sliding friction due to horizontal force caused by 1.0 ft swell head. The coefficient of friction for this condition should be assumed as 0.40 for steel on steel.

(d) Downward hydrostatic load due to 1.0-ft swell head.

(e) Weight of recess protection and trash screen minus weight of water displaced.

(f) Side seal friction based on a differential head of 1.0 ft plus preset force for approximately 3/4-in. deflection. The friction coefficient for rubber on steel is assumed to be 1.0.

(5) Typical calculations for determining loads for design of emergency gates are shown in Plate B-88 for the upstream leaf and in Plate B-89 for the downstream leaf.

(6) Loads used for design of vertical-tide gates are similar to the loads used for vertical-emergency gates except that the wind load is a more critical factor. The gate is hoisted high above the structure permitting barge traffic to pass underneath. This exposes the gate to a considerable wind load which must be included. To find the hoist capacity, the following two conditions should be considered and the condition creating the greater load should be used for design of the hoist.

(a) Condition I. Weight of gate leaf in water consisting of the skin plate, framing, sheaves and brackets, wheels, etc., and the weight of silt (125 pcf) trapped by the flanges of the gate girders less the weight of water displaced. Rolling friction of 5 percent of the horizontal load on the gate caused by the largest combination of differential head when the gate is lowered into position plus the wind load, at 20 psf, for the exposed portion of the gate.

(b) Condition II. Weight of the gate leaf in air consisting of the skin plate, framing, sheaves and brackets, wheels, etc., and the weight of silt (125 pcf) trapped by the flanges of the gate girders. Rolling friction of 5 percent of the horizontal load on the gate caused by the wind load, at 20 psf, for the exposed surface of the gate.

d. Operating machinery control. Control stations for vertical-lift gates are usually located adjacent to the gate along with the hoist machinery. The control equipment consists of the combination of full voltage magnetic controllers, limit switches, and control switches arranged to produce the desired operating sequence. The limit switches used in previous designs were usually of the traveling-nut type in the National Electric Manufacturers Association's four enclosures. Due to the unavailability of traveling-nut limit switches, cam-operated switches are being used. Slack cable limit switches and skew control and indication should be used on vertical-lift gates to prevent them from becoming stuck. Gate leaf control can be performed as indicated on the typical electrical schematic diagram for an emergency gate hoist (Plate B-73) or by using electronic devices such as position encoders, and position and speed tachometers.

Chapter 6
Submergible Tainter Gates

6-1. Design Analysis

The design of a submergible tainter gate is similar to that of a spillway tainter gate. Guidance in EM 1110-2-2702 should be followed. Navigation locks are wider and have lower forebay heads than spillway gates. Because of the greater lock widths, the gates main horizontal structural members will be trusses or plate girders. Secondary stresses in truss joints should be considered. Because of lock clearance requirements, trunnion anchorages are placed in lock wall recesses. Anchor bolts require special considerations in design. Eccentricity of hub alignment during construction introduces some additional stresses during gate operation. A typical navigation lock plate girder, submergible tainter gate is shown in Plates B-45 and B-46.

6-2. Seal and Gate Deicing

Devices for preventing the formation of ice, or to thaw ice adhering to the gates and seals, will be necessary for the lock to function during subfreezing weather. Lock operation in winter will be facilitated by the use of deicing (and trash clearing in all seasons) systems described.

a. Heaters. Two types of electric heating systems can be used for gate seals; one is by direct heating the seal by an electrical resistance element inserted below the seal face and the other by circulating electrically heated heat-transfer oil.

(1) Direct electrical heating. Replaceable heating elements can be installed in recesses in back of the seal surfaces to be kept thawed, the recesses being insulated so as to direct heat toward the surface to be heated. Because of the length of the sill seal and its inaccessibility, it is impractical to use this method across the bottom of the gate.

(2) Heating by circulating fluid. The usual method of seal heating is done by a design circulating heat-transfer oil through pipes built into the seal plates next to the surface to be thawed. Immersion-type electrical heating units, thermostatically controlled, heat the oil which is forced through the pipes by circulating pumps. The heating stations are located in the hoist machinery spaces at opposite ends of the gate.

b. Air deicing and trash clearing systems. Air nozzles at about 10-ft spacing and 4-ft³ free air per minute per nozzle terminate both upstream and downstream of the gate face. The air discharging from these nozzles carries the warmer water to the surface (when water temperature is below 39 deg F) and melts any ice buildup at the surface. This air system is most useful in clearing floating debris from the path of a rising gate at all times of the year. The air to the upstream nozzle sets is controlled by two sets of reducing valves to prevent one set from "hogging" to the lower outlet pressure. The upstream and downstream air control valves are separately operated from the gate control stand to be used at the discretion of the lock operating personnel.

6-3. Operating Machinery

a. General description. The machinery used to operate lock-type tainter gates usually consists of two equal hoist units of contra-facsimile design arranged to lift each end of the gate. The hoist units are kept in synchronism by power selsyn motors. Each hoist unit consists of a rope drum, open gear set, speed reducer, magnetic brake, hoist motor, and power selsyn. The drum is mounted on a cantilevered shaft of a size to prevent excessive error in the mesh of the final drive pinion and gear due to shaft deflection. A general arrangement of an electric-motor-driven hoist for the lock-type tainter gate is shown in Plate B-60.

b. Design considerations and criteria. The design capacity of the hoist should be based on the maximum load at normal speed which is found to be at the nearly closed or raised position. The hoisting speed should be selected so as to raise the gate from full open to closed in 2 to 3 min, varying so as to allow the selection of a motor of standard horsepower and speed. General criteria applicable to the design and selection of various hoist components are presented in paragraph 1-11. Shock, impact, and wear factors are considered negligible and may be disregarded. Wire rope for these types of hoists should be stainless steel, lang lay, style G, flattened strand. Drum diameter should not be less than 30 times the rope diameter.

c. Determination of machinery loads. The maximum dynamic load on the hoist normally occurs near the end of the raising cycle. The maximum holding rope load occurs when the gate is fully raised and the lock water level is below the upper sill. No consideration should be given to rope loads created by the flow of water over a partially opened gate. The rope loads from these conditions are

indeterminate and control features are provided to prevent their occurrence. The total load on the rope drum is the sum of the following:

(1) Deadweight of the gate as applied to a moment arm (W × CG) divided by the perpendicular distance of the rope to the gate trunnion center line.

(2) Side seal friction (total seal force × 0.05).

(3) Weight of the ropes can be neglected.

(4) Trunnion friction less than 200 lb can be neglected.

(5) The static load of the water head on the unbalanced area on the bottom seal when the lock level is down.

(6) Ice buildup and silt formation should be considered when severe freezing or silt-loaded water are factors. The air deicing and seal heating systems usually minimize these factors.

d. Operating machinery control.

(1) General. The electrical equipment for the operation of a power selsyn drive for the hoists for a tainter gate consists of two squirrel-cage induction-type motors, two wound rotor induction motors (synchronizing drive), two electrically operated brakes, two limit switches, and a control system that will provide operating features applicable to the particular installation. Equipment meeting the requirements of Guide Specification CW-14615 is considered to be the best suited for the service.

(2) Motors. The squirrel-cage induction motors should have high-torque high-slip (between 8 and 10 percent) speed torque characteristics with drip-proof frames as this equipment is usually located indoors. The drive motor should be continuous rated and sized to drive the gate machinery without overload during any portion of the operating cycle. No arbitrary limit should be placed on motor speed other than that which is practical and economical. The wound rotor motor for synchronizing shall be of the same horsepower rating as the drive motor, as it may be necessary, under some circumstances to provide the full torque of a drive motor. For the protection of the motor windings, means shall be taken to provide winding heaters or encapsulation. Motors should be specified in accordance with the applicable provisions of Guide Specification CW-14615.

(3) Brakes. The brakes should be of the shoe or split-band type, spring-set with direct current magnet-operated release, suitable for floor mounting and should be provided with NEMA 12 moisture-resisting, enclosing case. The brake mechanism should be of corrosion-resistant construction using nonferrous parts for bearings, pins, etc. The necessary direct current for operating the brake should be obtained from a rectifier mounted within the controller enclosing case. The torque rating of the brake should be of a value corresponding to approximately 150 percent of full load motor torque when referred to the shaft on which the brake wheel is mounted. A space heater should be provided within the brake enclosure as required in Guide Specification CW-14615.

(4) Control. The control equipment consists of a combination of magnetic controllers, limit switches, control stations, and remote gate position indication as shown in Plate B-74. The main control station (remote from the equipment) is located at the upstream control stand along with the other controls for the navigation lock. A local control station along with a local-remote transfer switch is located in one of the machinery rooms, and is provided for operation of the equipment during maintenance. The control equipment may be located where convenient but usually in one central location in a control center. The rotors of the two wound rotor motors are connected so that when the stators are energized from a common tie through a controller the rotors will rotate in a common direction, either raise or lower. When final adjustments are being made and the gate leveled, the rotors are synchronized with the couplings disconnected. The stators are energized first single-phase and then three-phase to pull the rotors into synchronism. Then the couplings are connected while the gate is in level condition supported on the ropes. During normal operation the drive motor, wound rotor motors, and brakes are all energized simultaneously and run until stopped by a limit switch in either the open or closed position or by the movement of a control switch to the stop position. During the stopping sequence, both the drive motors and brakes are de-energized but the wound rotor motors remain energized for a short time (5 sec) while the brakes are setting. This prevents skewing of the gate should the brakes set unevenly because of wear or misadjustment. A synchro system is used to show gate position at the control stand. A system of interlocks is used in the control circuit to prevent opening the gate at a time which might cause damage to the equipment or create hazardous conditions. Among these is a differential level circuit which will allow opening the gate only when the water surfaces on

either side of the gate are nearly at the same elevation. Control voltage is obtained from the control transformer whose primary is connected to the load side of the wound rotor motor supply which prevents gate operation unless synchronizing power is available. The controllers are of the combination air circuit breaker disconnect and reversing magnetic contactor type, with thermal overload protection. The limit switch should be of the heavy duty, high-accuracy type in order to ensure reliable operation of the control system.

Chapter 7
Corrosion Control

7-1. Corrosive Environment of Lock Gates

Lock gates are located in river water which is a submerged corrosive environment. Corrosion causes different degrees of structural and metallic deterioration of the gates. This affects operation and repair of the gates. Adequate coating (painting) and cathodic protection with protective potential achieving minus 850 millivolts "instant off" over 90 percent of each gate leaf face will extend the life of a lock gate leaf well over 100 years. (See Plates B-75 through B-78.)

7-2. Corrosion and Corrosion Control

a. Most of the time, the locks initially perform their function in spite of frequent use, floating impact, floods, and corrosion. The lock gates (usually miter type) are vital to the locking function and require periodic maintenance in such areas as the quoin and miter blocks, diagonals, lower areas of the gate, loss of gate plumb, and loss of seals. This is caused by flooding, waterborne impact, frequent use of equipment (under pressure and high velocity), loss of protective paint, and corrosion. These problems are usually resolved with expenditures or lock replacement. Since the gates are key operating elements, failure of their function causes disruption of river traffic. Repairs and/or replacement are very expensive. Because of this loss of service and high cost of dewatering, gate repair, and painting, it is becoming more important to ensure that cathodic protection is providing protective potentials.

b. Corrosion causes the lock gates and valve gates to deteriorate, and consequently preventative maintenance is required. Many times when corrosion causes the need for maintenance it is not attributed to the corrosion process.

c. A significant number of the maintenance problems can be delayed, and even prevented, with effective coating and cathodic protection. It can be established that lock gates can be protected from the devastating effects of corrosion with proper coating and cathodic protection. While it is true that this does not place the lock gates in a perpetual state of corrosion prevention, and while it will not undo earlier deterioration due to corrosion, it is a fact that a properly maintained and adjusted cathodic protection system will decrease the need for many lock repairs and prevent the expensive lock facility from becoming obsolete by deterioration. The initial expense of installing cathodic protection and the expense of regular maintenance of the systems can easily be shown to provide a very high cost-benefit ratio.

7-3. Painting Structures

a. The primary corrosion control system for lock gates is painting. The paint protects some areas of the lock gate components. This provides some degree of corrosion protection. When paint is scratched and cut with waterborne impact, metal surfaces or holidays are exposed to the corrosive electrolyte. The base surface areas become anodes and will corrode in a concentrated area. This affects the limit states of strength and serviceability of the steel in the gates. The corroded area is manifest in operation and maintenance of lock gates.

b. The following approaches should be used to improve the painting system and ensure its durability:

(1) Determine that the surfaces to be painted have rounded edges and corners, and smooth joints.

(2) Avoid waterborne impact.

(3) Install cathodic protection to protect the exposed areas of the steel.

c. Environmental concerns have caused some restrictions on metal preparation and application of quality paints used in the past which are also presently being used when possible. The environmental concerns have resulted in poorer quality of paint on the market.

(1) Recently, a study at the Construction Engineering Research Laboratory (CERL), Champaign, Illinois, was made on a large number of different paints on the market. The paints studied represented most current approaches to painting and some new, highly touted paints that met environmental concerns.

(2) Most of these paints failed in the laboratory tests. Only a small number of the best were selected for field tests. In field tests (in water environment and submerged), these paints did not perform well when compared to paints presently being used (vinyl). Future environmental concerns will further restrict or eliminate the use of presently applied paints. Only in certain areas of several states are those restrictions in effect at this time. This, of course, emphasizes the importance of cathodic protection and painting where needed.

(3) With the advent of poorer quality paint, the proper installation and maintenance of cathodic protection will become much more critical. The paint quality for submerged metals is becoming a serious problem because of environmental controls of cleaning and painting metal. Corroded metal structures could cause unsafe and wasteful operation of facilities. Periodic inspections help to identify potential unsafe conditions, deteriorating conditions, and equipment not working. Cathodic protection equipment should be working. Periodic inspection reports on civil works structures should include the most recent dated electrolyte potential survey, condition of cathodic protection system, and plans for cathodic protection system repair and modification if required.

(4) Future emphasis on limiting dewatering of locks is another factor that increases the importance of operational cathodic protection.

7-4. Type of Cathodic Protection

a. Impressed current. Cathodic protection for lock gates should be provided utilizing Guide Specification CW-16643. Cathodic protection should be impressed current and should have good impact protection to protect the anodes from waterborne impact.

b. New techniques. Guide Specification CW-16643 provides new techniques for impact protection and for achieving operational cathodic protection systems, and addresses methods of providing protection against ice and debris, steps to increase quality construction, and training on design, installation, operation, and maintenance of cathodic protection systems.

c. Cathodic-protection testing, evaluation, and restoration. All testing, evaluation, restoration, or new installation should be supervised by a professional engineer registered in corrosion engineering, or an individual who has satisfied the requirements for accreditation as a corrosion technologist or specialist by the National Association of Corrosion Engineers (NACE). Installation of the cathodic protection systems should also be witnessed by appropriate Government representatives qualified in cathodic protection.

d. Restoration of cathodic-protection systems. Existing inoperable cathodic-protection systems at many navigation structures can be restored. This approach is less expensive than installing complete new cathodic protection systems and, therefore, should be considered first. When graphite anode strings are exhausted, they should be replaced with cast iron anode strings. In many cases anode strings can be replaced and cathodic-protection systems repaired without dewatering.

e. Complete replacement of cathodic-protection systems. Guide Specification CW-16643 should be followed when designing and installing new cathodic-protection systems or when complete replacement of cathodic-protection systems at navigation structures is found to be necessary.

7-5. Cathodic-Protection Operation

An impressed current cathodic-protection system should be provided for each gate leaf. Each system consists of a rectifier supplying protective voltages to anodes which will distribute uniform protective voltages through the river water to the submerged gate structure. Cathodic-protection should be installed on those portions of the gates submerged at normal pool levels. The faces of the gates are protected to upper pool stages, except that the downstream face of the lower gates shall be protected to the lower pool. Meters are provided as part of the rectifier for monitoring of the cathodic-protection systems. Surveillance of the rectifier output (voltage and current) is required to ensure that the rectifier unit operates on a continuous basis at the desired output levels. Voltage and current indications with the lock chambers filled provide surveillance of the rectifier and cathodic-protection operation. The cathodic-protection systems will encounter flooding and floating debris and will require impact protection to prevent damage to the cables providing voltage to the anodes.

7-6. Anode Concepts

One of two basic concepts for providing cathodic protection should be used. Method one uses cast iron button anodes on the skin plate and string type (sausage) anodes in the compartment areas. The sausage anodes and cables are protected from impact by installing them in perforated plastic pipes and in areas subject to ice and debris by installing channel and angle iron in front of each anode string. The button anode cables are protected from impact with conduit. The cast iron button anodes are more durable and can withstand impact. The second method uses cast iron button anodes in all areas.

7-7. Flooding and Emergency Maintenance

The rectifiers are portable (normally with wheels) so that during flooding conditions they may be removed and safeguarded from water or storm damage.

7-8. Cathodic-Protection Tests, Adjustments and Reports

a. Tests, adjustments, and data collection. Tests should be performed and data tabulated showing structure to reference cell potentials at a number of different points. Test data should include rectifier voltages and currents. There is no prescribed time interval for testing new systems, but as a general rule measurements should be made monthly until steady state conditions are obtained, and at about 6-month intervals thereafter for the first year or two; and thereafter at least at yearly intervals, depending on the judgment of the corrosion engineer responsible for the tests. Based upon the measurements taken, the current and voltage of the rectifier should be adjusted as required to produce a minimum of minus 850 millivolts "instant off" potential between the structure being tested and the reference cell. This potential should be obtained over 90 percent of each face of each gate leaf. This must be achieved without the "instant off" potential exceeding 1,200 millivolts. Acceptance criteria of the cathodic-protection systems are defined in the National Association of Corrosion Engineers Publication NACE RP-01-69-92.

b. Reports. Reports in a format similar to that illustrated in NACE RP-01-69-92 (see Table 7-1) of a miter gate showing the measurements made and data obtained, should be prepared and evaluated.

7-9. Measurement of Existing Cathodic-Protection Systems

The performance of existing systems should be measured annually and appropriate actions taken.

a. One structure to electrolyte potential survey (using reference cell) should be performed annually. Any system found to not be operating in accordance with established criteria should be optimized (adjusted).

b. Any cathodic protection system found to be in need of repair should be repaired.

c. A report showing the condition of the cathodic protection systems, and/or plans to repair the systems, should be submitted each year.

7-10. Cathodic Protection for Miter and Quoin Blocks

One of the most expensive maintenance problems that occurs on lock gates is corrosion of the miter and quoin blocks. This can be prevented with impressed current anode strings in the vicinity of the miter and quoin blocks. Guide Specification CW-16643 provides drawings showing anode locations I-1 anode string 2S1 and 1S1 that can provide voltage sufficient to protect the miter and quoin blocks. All areas of the miter block and push-pull rods should be painted. The area where the blocks seal against each other does not have to be painted.

Table 7-1
Steel to Reference Cell Potentials

Rectifier No. 1
UPPER GATE - LAND LEAF - UPSTREAM SIDE
(Impressed Current Installation)
REPORTS CONTROL SYMBOL ENGW-E-7
DATE OF TEST: 1 Oct. 1991

Pre-Protection				Current On			Current Off (Instant Off)		
Depth Below Water Surface	Quoin End	Middle	Miter End	Quoin End	Middle	Miter End	Quoin END	Middle	Miter End
0'-6"	-0.500	-0.505	-0.495	-1.050	-1.000	-1.055	-0.655	-0.700	-0.650**
2'	-0.500	-0.500	-0.500	-1.040	-1.030	-1.035	-0.700	-0.735	-0.705
4'	-0.500	-0.500	-0.500	-1.050	-1.085	-1.050	-0.825	-0.755	-0.815
6'	-0.500	-0.495	-0.495	-1.050	-1.100	-1.055	-0.855	-0.765	-0.850
8'	-0.495	-0.490	-0.490	-1.050	-1.085	-1.050	-0.865	-0.770	-0.850
10'	-0.490	-0.480	-0.485	-1.080	-1.110	-1.070	-0.880	-0.880	-0.850*
12'	-0.490	-0.480	-0.480	-1.070	-1.080	-1.060	-0.885	-0.880	-0.880
14'	-0.480	-0.479	-0.470	-1.070	-1.070	-1.065	-0.880	-0.885	-0.980
16'	-0.470	-0.464	-0.460	-1.000	-1.020	-1.030	-0.885	-0.890	-0.980
18'	-0.465	-0.455	-0.450	-1.000	-0.979	-1.050	-0.880	-0.885	-0.985
20'	-0.460	-0.445	-0.440	-0.950	-0.930	-1.000	-0.870	-0.875	-0.1075

Rectifier voltage = 2.10 volts
Rectifier current = 0.50 amps
Coarse tap position = L
Fine tap position = 2
Meter used 5 meg ohms/volt 2 volt scale
Half-cell 0'-3" or less from lock steel
Resistance of circuit: $E = IR$
$2.10 = .5R$
$R = 2.10/.5 = 4$ ohms

* Acceptable reading
** Unacceptable reading

NOTE: Include as many 2' increments as necessary to cover submerged depth of gate.

Appendix A
References

A-1. Required Publications

Note: References used in this EM are available on interlibrary loan from the Research Library, ATTN: CEWES-IM-MI-R, U.S. Army Engineer Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199.

Federal Specification QQ-C-390B
Copper Alloy Castings (Including Cast Bar)

Federal Specification FF-S-325
Shield, Expansion; Nail, Expansion; and Nail Drive Screw (Devices, Anchoring, Masonry)

TM 5-809-1
Load Assumption for Buildings

EM 1110-2-2105
Design of Hydraulic Steel Structures

EM 1110-2-2608
Navigation Locks-Fire Protection Provisions

EM 1110-2-2702
Design of Spillway Tainter Gates

EM 1110-2-3400
Painting: New Construction and Maintenance

CW 05036
Metallizing, Hydraulic Structures and Appurtenant Works

CW 05501
Metalwork Fabrication, Machine Work and Miscellaneous Provisions

CW 05502
Miscellaneous Metal Materials, Standard Articles and Shop Fabricated Items

CW 09940
Painting: Hydraulic Structures and Appurtenant Works

CW 11290
Hydraulic Power Systems for Civil Works Structures

CW 14615
Electrical Equipment for Gate Hoists

CW 16643
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Appendix B
Illustrative Plates

B-1. Illustrative Plates

   a. *General information and typical details.*

NOTE: GATE IN OPEN POSITION

SECTION A-A

QUOIN POST
SECTION B-B

SECTION C-C

DOWNSTREAM ELEVATION

MITER GATES
HORIZONTALLY FRAMED
GENERAL ELEVATION
AND SECTIONS

NOTE: GATE IN CLOSED POSITION

NOTE: INTERMEDIATE FENDERS
ARE NOT SHOWN

FLOW

TOP GIRDER

SKIN PLATE

VERTICAL BEAM

BOTTOM
GIRDER

SILL

SECTION A-A

END VIEW

HORIZONTAL
GIRDER

MITER
WATER
SEAL

HORIZONTAL GIRDER

LOCK ℄

HANDRAIL

BULKHEAD PLATE

GUSSET PLATES

DOWN STREAM ELEVATION

℄ OPERATING STRUT

WALKWAY

PLAN

FLOW

ANCHORAGE

℄ PINTLE

DIAGONALS

QUOIN
BLOCK

QUOIN
WATER
SEAL

T₁

T₂

A

A

INTERCOSTAL

SKIN PLATE

VERTICAL
BEAM

SKIN PLATE DETAIL

MITER GATES
VERTICALLY FRAMED
GENERAL PLAN AND
ELEVATION

FLOW

P_2 P_1

R

¢ LOCK

N

$W = \omega L$

THRUST LINE

RADIUS

t_j

O

4' W.L.

ASSUMED

L

X — X

X

ϕ

3
4
3

N

P_2 P_1 ω

R

PLAN OF TYPICAL HORIZONTAL GIRDER

WITH A MITER SLOPE OF 1 L ON 3 T

L = LENGTH OF LEAF, CONTACT TO CONTACT, IN FEET

t_j = DISTANCE FROM WORK LINE (W.L.) TO OUTSIDE OF DAMMING SURFACE, IN FEET

ω = WATER LOAD PER LINEAR FOOT

MOMENT IN GIRDER $= M_x = \left[N(x) - \dfrac{\omega(x)^2}{2} \right] + \left[P_2 \times \dfrac{t_j}{2} \right]$ @ POINT O

$M\mathcal{C} = N\left(\dfrac{L}{2}\right) - \dfrac{\omega(L)^2}{8} + P_2\left(\dfrac{t_j}{2}\right)$; $e' = \dfrac{M}{P} \times 12$; $e = e' + (4.0 + D.S. \, ft \, t) - C_1$ $(e'$ AND e IN INCHES)

$f_a = \dfrac{P}{A}$; $f_b = \dfrac{Pe}{S}$

THE SIGN OF e INDICATES WHETHER THE UPSTREAM OR DOWNSTREAM FLANGE IS IN COMPRESSION

$(+)$ U.S. FLANGE IN COMPRESSION ; $(-)$ D.S. FLANGE IN COMPRESSION

$W = \omega L$
$R = 1.58 W$
$N = 0.50 W$
$P_1 = 1.5 W$
$P_2 = t_j W / L$
$P = P_1 + P_2$
L = LONGITUDINAL
T = TRANSVERSE
t = FLANGE THICKNESS
S_1, S_2 = SECTION MODULUS.

THRUST LINE
WIDTH = FLANGE WIDTH PLUS EFFECTIVE SKIN PLATE WIDTH $d = 95 / \sqrt{F_y}$

WIDTH = 24 t (MAXIMUM)

WIDTH = 24 t (MAXIMUM)
WORK LINE
(SEE PLATE B-5 FOR DETAILS
OF BOTTOM GIRDER)

e e' C_1 S_1

d C_2 S_2

d

N.A. = NEUTRAL AXIS OF GIRDER

MITER GATES
HORIZONTALLY FRAMED
TYPICAL GIRDER DATA

PLATE B-3

GEOMETRY FOR LOCATING PINTLE
SCALE: 1½"=1'-0"

NOTES

1. DIMENSIONS AND DETAILS ARE TYPICAL AND ARE USED FOR AN EXPLANATION ONLY. DIMENSIONS MAY VARY AS REQUIRED BY GATE SIZE. FOR GEOMETRY, SEE APPENDIX C.

MITER GATES
HORIZONTALLY FRAMED
PINTLE AND RECESS
GEOMETRY

PLAN
SCALE: ½"=1'-0"

TAPERED END SECTION LAYOUT
SCALE: 1"=1'-0"

NOTE:
NUMBERED POINTS ARE USED IN COORDINATE GEOMETRY COMPUTATIONS TO ESTABLISH PINTLE LOCATION AND RECESS OUTLINE. SEE APPENDIX C FOR EXAMPLE PROBLEM.

GIRDER FLANGE DATA

BOTTOM GIRDER DOWNSTREAM FLANGE (OPTIONAL TO PROVIDE ADDITIONAL CLEARANCE TO SILL)

SECTION THROUGH BOTTOM GIRDER

ALL GIRDERS EXCEPT BOTTOM BOTH UPSTREAM AND DOWNSTREAM FLANGES

BOTTOM GIRDER UPSTREAM FLANGE

THRUST DIAPHRAGM STIFFENER PLATE

THRUST DIAPHRAGM

WORK LINE

QUOIN POST

CONTACT POINT

WIDTH OF END PLATE IS THE WIDTH OF WEB PLUS THE FLANGES, PLUS ¼" EXTENSION ON EACH SIDE (FOR WELDING)

* 1" THICKNESS MINIMUM ON END PLATE

NOTE "A"
THE ECCENTRICITY OF CENTER LINE OF PINTLE RELATIVE TO THE THRUST LINE AS SHOWN IS FOR AN EXISTING GATE. AN ECCENTRICITY OF 7" IS RECOMMENDED FOR NEW CONSTRUCTION. ALSO SEE CHAPTER 2, PAR. 2-1h.

MITER GATES
HORIZONTALLY FRAMED
QUOIN POST AND TYPICAL
DATA FOR GIRDER FLANGES

PLATE B-5

PR- 3/4

9"

1'-4"

OF ANCHORAGE

BORE DIA. 12.000" +.006 / -.000

(12.0" DIA. PIN MIN.)
R-I (MIN.)

6 1/2"

1'-0"

9"

1'-6"

SECTION A-A

PR- 3/4

9"

1'-4"

OF ANCHORAGE

6 1/2"

1'-0"

9"

1'-6"

SECTION A-A
ALTERNATE

* SEE NOTE "A" ON PLATE NO. 5

PR- 3/4

3'-1"

* VARIES WITH WEB DEPTH

(APPROX. 4'-0 FOR 4'-6 WEB)

PR- 3/4

NOTCH STIFFENER PLATE
TO CLEAR HOOD PLATE

PLAN

RADIUS TANGENT
TO UPSTREAM
FLANGE

PR- 3/4

2 1/4"

1'-2 3/32"

A

B

GUDGEON PIN CONNECTION

PR- 1/2
PR- 3/4

PR- 3/4

PIN PR- 1 1/4

WEB PR

THRUST PR

FLANGE PR

PR- 6 x 1/2

SECTION B-B

PR- 3/4

1" DIA DRAIN HOLE
IN TOP GIRDER

PR- 3/4

BORE DIA. 12.000 "+.006 / -.000"

2" DIA. DRAIN HOLE
IN TOP GIRDER

1'-4 3/8"

1'-0"

A

PIN PR- 1/4

BULKHEAD PR- 2

4"

1'-4"

1'-5"

7"

10 3/8"

2'-5 1/4 ±

1'-1 1/2"
WEB

6 1/8"
WEB

1"

SECTION SHOWING PIN PLATE

DIMENSIONS SHOWN ARE SUGGESTED
DIMENSIONS ONLY AND MAY BE VARIED
SLIGHTLY WHERE NECESSARY.

MITER GATES
HORIZONTALLY FRAMED
GUDGEON PIN HOOD

FROM: "ADVANCED MECHANICS OF MATERIALS" BY SEELY AND SMITH (1952)
2ND EDITION, PAGE 185

a = AREA OF SECTION

d = MEAN DIAMETER OF RING w = UNIT LOAD

W = TOTAL VERTICAL LOAD $\frac{1}{2} P = wR$

y = DISTANCE FROM CENTROIDAL AXIS, (y) IS NEGATIVE TOWARD THE INNER FACE AND POSITIVE TOWARD THE OUTER FACE
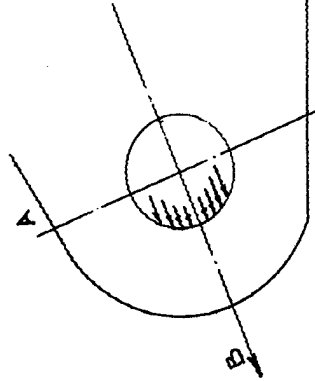
$R = d/2$

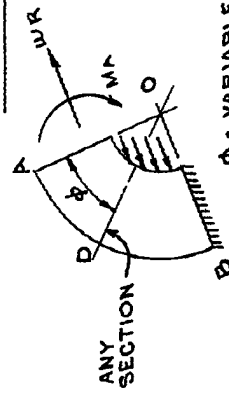MOMENT

$$M_A = \frac{1}{16} Wd \qquad M_B = -\frac{Wd}{16}$$

STRESS

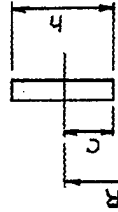$$S = \frac{\frac{1}{2} P \cos \phi}{a} + \frac{M}{aR}\left(1 + \frac{1}{Z}\ \frac{y}{R+y}\right)$$

$$\text{FACTOR OF } Z = (-)1 + \frac{R}{h}\left[\log_e\left(\frac{R+c}{R-c}\right)\right]$$
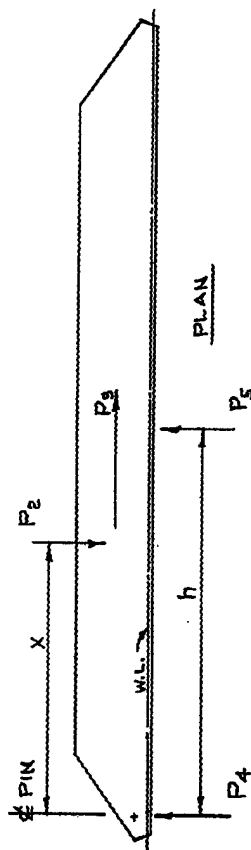

PLAN OF GUDGEON PIN HOOD

UNIFORM LOAD

AXIS OF CURVATURE

ANY SECTION

ϕ = VARIABLE

ANCHORAGE LINKS

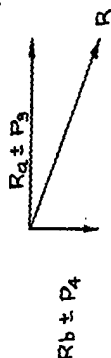**PLAN**

ELEVATION

END VIEW

P_2 = STRUT FORCE COMPONENT PERPENDICULAR TO THE WORK LINE OF THE LEAF
P_3 = STRUT FORCE COMPONENT PARALLEL TO THE WORK LINE OF THE LEAF
P_4 = REACTION OR APPLIED FORCE CREATED BY P_2
P_5 = WATER RESISTANCE ON LEAF
X = 20'-0" FOR 110'-0" LOCKS WITH "PANAMA CANAL" TYPE MACHINE
h = LENGTH OF LEAF MINUS DISTANCE FROM CONTACT TO PINTLE, DIVIDED BY 2
v = VERTICAL DISTANCE BETWEEN PIN REACTION AND PINTLE REACTION

$$P_5 = \frac{X(P_2)}{h}$$

$$P_4 = P_2 - P_5$$

MAXIMUM FORCE ON GUDGEON PIN

$$R_a \pm P_3$$

$$R_b \pm P_4$$

FORCE ON PIN = R + 10% IMPACT

LOAD ON PINTLE DUE TO WT.:
$$A = \frac{WT. \times h}{k} = \sqrt{Av^2 + A_H^2}$$
$$A_V = WT.$$
$$A_H = R_a$$
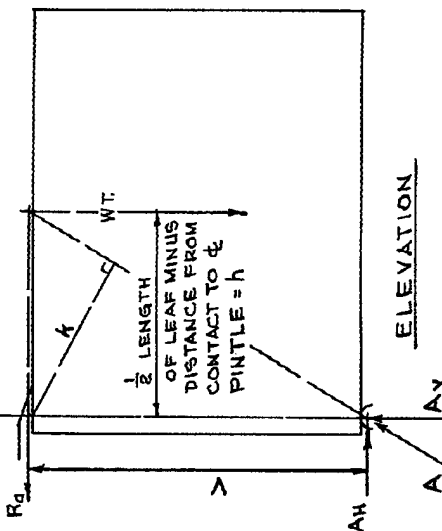
$$R_a = \frac{WT. \times h}{v}$$

WEIGHT MAY INCLUDE ICE AND MUD LOAD IF APPROPRIATE

d = DISTANCE FROM CENTER OF GRAVITY OF LEAF TO CENTER LINE OF PINTLE

$$R_b = \frac{WT. \times d}{v}$$

D.S. SIDE

½ LENGTH OF LEAF MINUS DISTANCE FROM CONTACT TO ℄ PINTLE = h

MITER GATES
HORIZONTALLY AND
VERTICALLY FRAMED
ANCHORAGE LINKS
DESIGN DATA

PLATE B-8

ANCHORAGE LINKS

BARREL

STIFFENER

$3.99'' = \frac{1}{2}$

$\frac{S_2}{S_1}$

PLAN

$A = 10.98''^a$
$C_1 = 4.27''$
$C_2 = 2.23''^3$
$S_1 = 9.44''^3$
$S_2 = 18.08''^3$
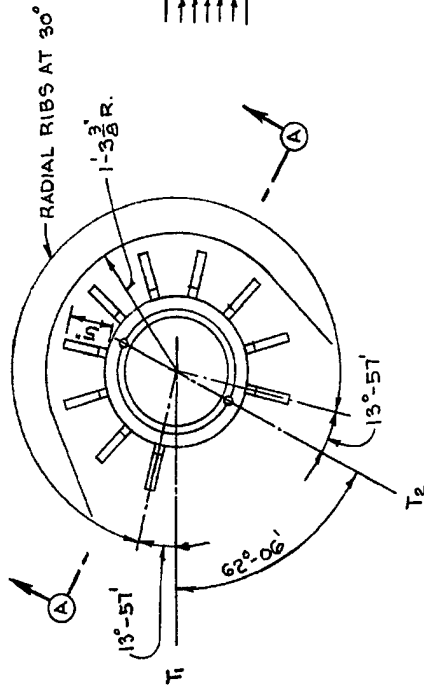$I = 40.30''^4$

DIMENSIONS SHOWN ARE TYPICAL AND ARE USED FOR EXPLANATION. DIMENSIONS MAY VARY WHERE NECESSARY.

MAXIMUM REACTION ON STIFFENERS

$\frac{1}{2}''$

$5''$

$6\frac{1}{4}''$
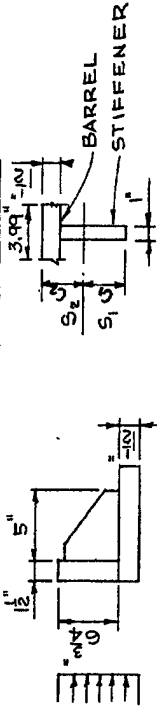
ELEVATION

CHECK STIFFENER AS A CANTILEVER BEAM WITH THE LOAD BEING THE MAXIMUM REACTION ON A STIFFENER.

$\frac{6.875''}{1.500}$

$\frac{8.375}{8.38}''$

$6.875 = 6.88''$

$\frac{1}{2} \times 7$ (HORIZONTAL PLATE)

N.A.

$R = 15.375''$

$1.65''$

$1.50''$

$R = 6.875''$ TO INSIDE OF BARREL
$1\frac{1}{2} \times 15$ (SECTION OF BARREL)

CENTROID 2.10''

HORIZONTAL PLATE AND BARREL SECTION

RADIAL RIBS AT 30°

$1 - 3\frac{3}{8}''$ R.

$13° - 51'$

A

A

$62° - 06'$

$13° - 51'$

T_2

T_1

PLAN

DIA. $1 - 4\frac{3}{4}''$
DIA. $1 - 1\frac{1}{2}''$
DIA. $12.000'' ^{+0.006}_{-0.000}$

$1\frac{1}{2}''$

GUDGEON PIN

₵ GUDGEON PIN

SECTION A-A

BUSHING, BRONZE

GREASE GROOVES,
ALL $\frac{1}{8}''$ DEEP

$1'' \times \frac{3}{4}''$ DIA. DOWEL

ω = EQUIVALENT FORCE AT THE ₵ OF THE BARREL

THICKNESS	$\omega = {}^{\#}/_{□}''$									
1	2	3	4	5	6	7	8	9	10

LOCAL BENDING IN BARREL

MITER GATES
HORIZONTALLY AND
VERTICALLY FRAMED
ANCHORAGE LINKS
GUDGEON PIN BARREL

ANCHORAGE LINKS

ALTERNATE METHOD OF PIN BARREL ANALYSIS

ASSUME THE COMPOSITE SECTION OF THE BARREL AND HORIZONTAL PLATE ACTS AS A CURVED BEAM WITH A UNIFORM LOADING ACROSS THE DIAMETER. (WHERE R IS TO THE CENTROID, AND D = 2R)
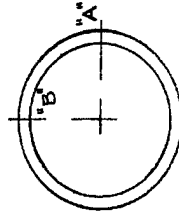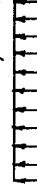
SEE "ADVANCED MECHANICS OF MATERIALS, SEELY & SMITH, (1952) 2ND. ED.

MA AND MB ARE MAXIMUM MOMENTS   MA = −MB

$$M_A = \frac{wR^2}{4} = \frac{Wd}{16}$$

r_o = RADIUS TO NEUTRAL AXIS

$$r_o = \frac{A}{\int \frac{dA}{r}} = \frac{(7 \times \frac{1}{2}) + (15 \times \frac{1}{2})}{15 \int_{6.88}^{8.38} \frac{dr}{r} + 1.5 \int_{8.38}^{15.38} \frac{dr}{r}}$$

$$r_o = \frac{33.0}{(15 \times Log_e \frac{8.38}{6.88}) + (1.5 \, Log_e \frac{15.38}{8.38})} = 8.53''$$

Y = DISTANCE FROM NEUTRAL AXIS TO THE POINT OF STRESS

$$M = \frac{SR}{Y} \int (r - r_o) dr \qquad S = \frac{MY}{R \int (r - r_o) dr}$$

$$S = \frac{\overset{WIDTH \, OF}{BARREL}}{R \left[15 \int_{6.88}^{8.38} r \, dr - \underset{(171.68)}{127.95} \int_{6.88}^{8.38} dr + 1.5 \int_{8.38}^{15.38} r \, dr - \underset{(124.74)}{12.80} \int_{8.38}^{15.38} dr \right]}$$

$$\int r \, dr = r^2/2$$

$$15 \int_{6.88}^{8.38} r \, dr = 15 \left[\frac{(8.38)^2}{2} - \frac{(6.88)^2}{2} \right] = 171.68$$

$$127.95 \int_{6.88}^{8.38} dr = 127.95 \left[(8.38 - 6.88) \right] = 191.93$$

$$1.5 \int_{8.38}^{15.38} r \, dr = 1.5 \left[\frac{(15.38)^2}{2} - \frac{(8.38)^2}{2} \right] = 124.74$$

$$12.80 \int_{8.38}^{15.38} dr = 12.80 \left[(15.38 - 8.38) \right] = 89.60$$

MAX. STRESS = (DIRECT TENSION) + (CURVED BEAM STRESS)

(POINT A, INSIDE FACE) + (LOCAL BENDING IN BARREL)

$$S = \frac{M \times Y}{R \times 14.89} \qquad \text{(FOR THE EXAMPLE SHOWN)}$$

(R IS THE RADIUS TO THE POINT UNDER CONSIDERATION)

(Y IS THE DISTANCE FROM THE NEUTRAL AXIS)

MITER GATES
HORIZONTALLY AND
VERTICALLY FRAMED
DESIGN DATA
ANCHORAGE LINKS
GUDGEON PIN BARREL

PLATE B-10

ANCHORAGE LINKS

DIMENSIONS SHOWN ARE TYPICAL AND ARE USED FOR EXPLANATION.
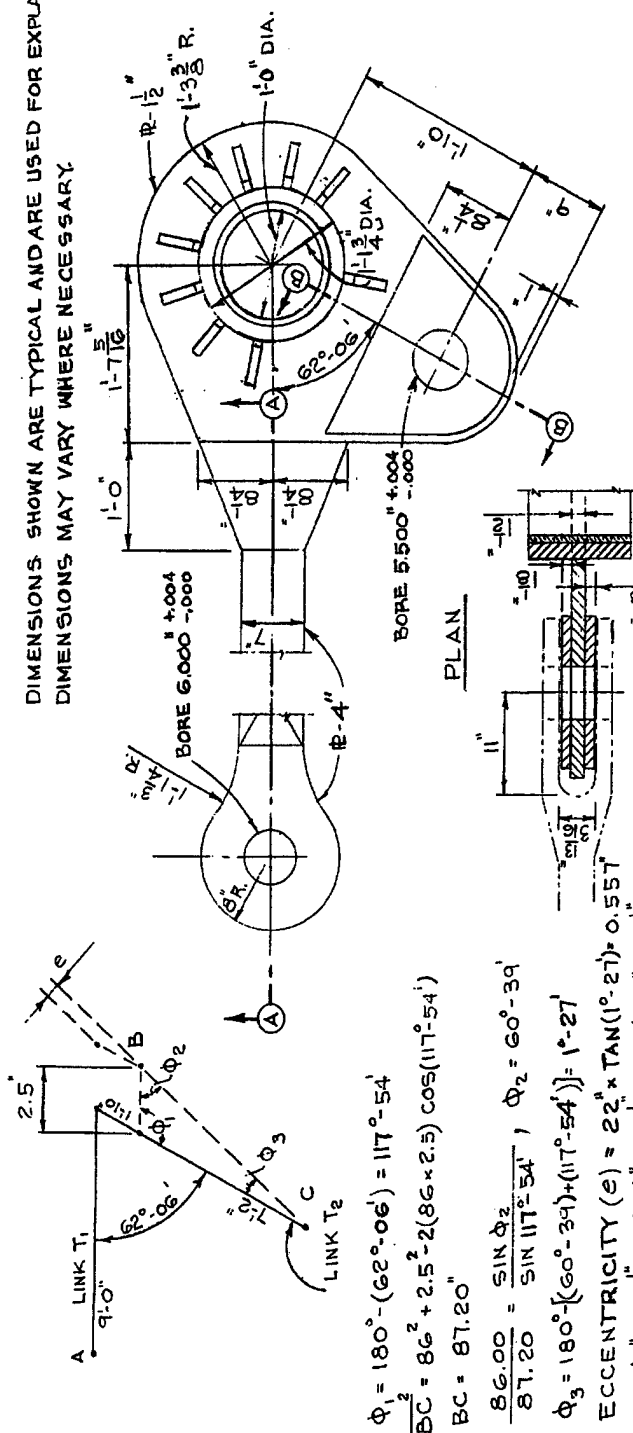DIMENSIONS MAY VARY WHERE NECESSARY.

R-1½"

1'-3⅜" R.

1'-0" DIA.

1⅜" DIA.

62°-06'

$1-7\frac{5}{16}$"

1'-0"

9"

BORE 6.000" +.004 -.000

BORE 5.500" +.004 -.000

PLAN

SECTION B-B

11"

THE RECTANGULAR BAR SECTION MAY BE MADE A MINIMUM OF 6"x4" WITH THE RELATED RADII AND THREADED DIAMETERS CHANGED ACCORDINGLY.

8" R.

LINK T_2

LINK T_1

A

9'-0"

2.5'

e

B

Φ_2

Φ_1

Φ_3

C

62°-06'

$\Phi_1 = 180° - (62°-06') = 117°-54'$

$\overline{BC} = 86^2 + 2.5^2 - 2(86 \times 2.5) \cos(117°-54')$

$\overline{BC} = 87.20"$

$\dfrac{86.00}{87.20} = \dfrac{\sin \Phi_2}{\sin 117°-54'}$, $\Phi_2 = 60°-39'$

$\Phi_3 = 180° - [(60°-39') + (117°-54')] = 1°-27'$

ECCENTRICITY $(e) = 22" \times \text{TAN}(1°-27') = 0.557"$

$5\frac{1}{2}"$ $1'-1\frac{1}{4}"$ $\frac{9}{64}"$ $1'-1\frac{1}{4}"$ $5\frac{1}{2}"$

1'-0"

7" DIA.-5 THD/INCH

HEX SLEEVE NUT

10"

6"

10"

4" DIA.

GREASE HOLE (PLUG)

SECTION A-A

MITER GATES
HORIZONTALLY AND
VERTICALLY FRAMED
ANCHORAGE LINKS
DESIGN DATA

PLATE B-11

VIEW A-A

VARIABLE

VARIABLE

VARIABLE
(SHOULD BE AS SHORT AS PRACTICAL)

VARIABLE

VARIABLE

$2''$ MIN.

$2''$ MIN.

$\frac{3}{4}''$ MINIMUM PLATE THICKNESS

BOLTS UNBONDED (PRESTRESSED)

ENTIRE SURFACE UNBONDED

PLATE TO BE CHECKED FOR UPLIFT AS WELL AS BEARING

BOLTS UNBONDED (PRESTRESSED)

ELEVATION

FORCE

$9.0'$

$12.73'$

$9.0'$

P_1

$P_2 V$

$P_2 H$

P_2

$P_2 = FORCE \div 0.707$

$P_1 = P_2 H = P_2 V = FORCE$

END VIEW

MITER GATES
HORIZONTALLY AND
VERTICALLY FRAMED
EMBEDDED ANCHORAGE

PLATE B-12

PINTLE BASE
(LOWER MITER GATE)

DIMENSIONS SHOWN ARE TYPICAL AND USED FOR
EXPLANATION ONLY. DIMENSIONS MAY VARY WHERE
NECESSARY.

FACE OF LOCK WALL

C̸ OF PINTLE PARALLEL TO SILL

SEAL LINE

20°

SILL ANGLE

PLAN

2'-0⅞"

45°

90°

C̸ PINTLE

1'-8" R

PINTLE SOCKET

GREASE RETURN LINE ; DRILL ½" DIA. TYP.

⅝" x ½" ANNULAR GREASE PICK-UP GROOVE

DRILL AND TAP FOR ½" DIA. LUBE LINE

KEEPER RING

C̸ SCREW PATTERN

PINTLE

3/16" GREASE GROOVES AT 50° CTRS.

THRUST PLATE 1¼ x 12 WIDE

MILLED BEARING SURFACE

C̸ WEB

PINTLE BUSHING

SEE DETAIL A

PINTLE SHOE

PINTLE BASE

2" DIA. CORED HOLES (TYP)

EPOXY OR ZINC FILLER

GATE REACTION

10" R

DETAIL A

QUOIN SEAL

PINTLE SOCKET

PINTLE

CENTROID OF HORIZONTAL BEARING AREA

SECTION THRU PINTLE ASSEMBLY

AREA OF ½ CIRCLE = $\frac{\pi D^2}{8}$

$I = 0.109757 R^4$

$m = 0.424413 R$

AREA OF ½ ELLIPSE = $\frac{\pi ab}{2}$

$I = b a^3 (\frac{\pi}{8} - 8/9\pi)$

$n = 4a/3\pi$

WEIGHT

$r \cdot \sin\phi$

R_H

R

r

ϕ

PINTLE

R_H IS THE RESULTANT OF R_a AND R_b SEE PLATE B-8

REF. AXIS

a

a

b

b

PROJECTED AREA

BEARING ON BUSHING

MAXIMUM = $\frac{R}{A} + \frac{Mc}{I}$

MINIMUM = $\frac{R}{A} - \frac{Mc}{I}$

MITER GATES
HORIZONTALLY FRAMED
LOWER GATE
FLOATING PINTLE
ASSEMBLY

PINTLE BASE
(UPPER MITER GATE)

DIMENSIONS SHOWN ARE TYPICAL AND USED FOR
EXPLANATION ONLY. DIMENSIONS MAY VARY WHERE
NECESSARY

FACE OF LOCK WALL

℄ OF PINTLE PARALLEL TO SILL

SILL PLATE

2'-0½"

2½"

2½"

45°

30°

20°

2'-½" R
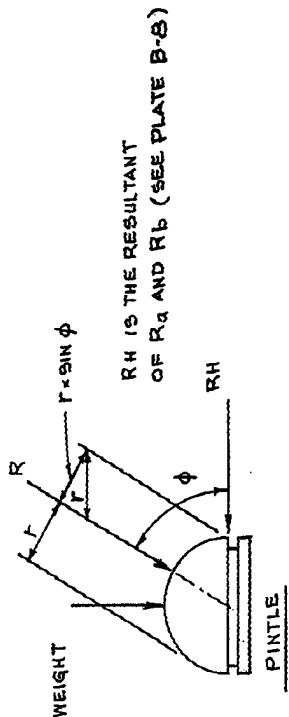
11" R

8" R
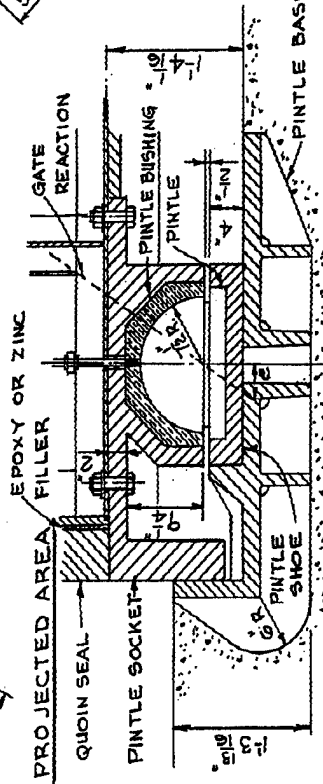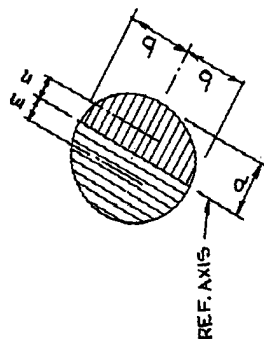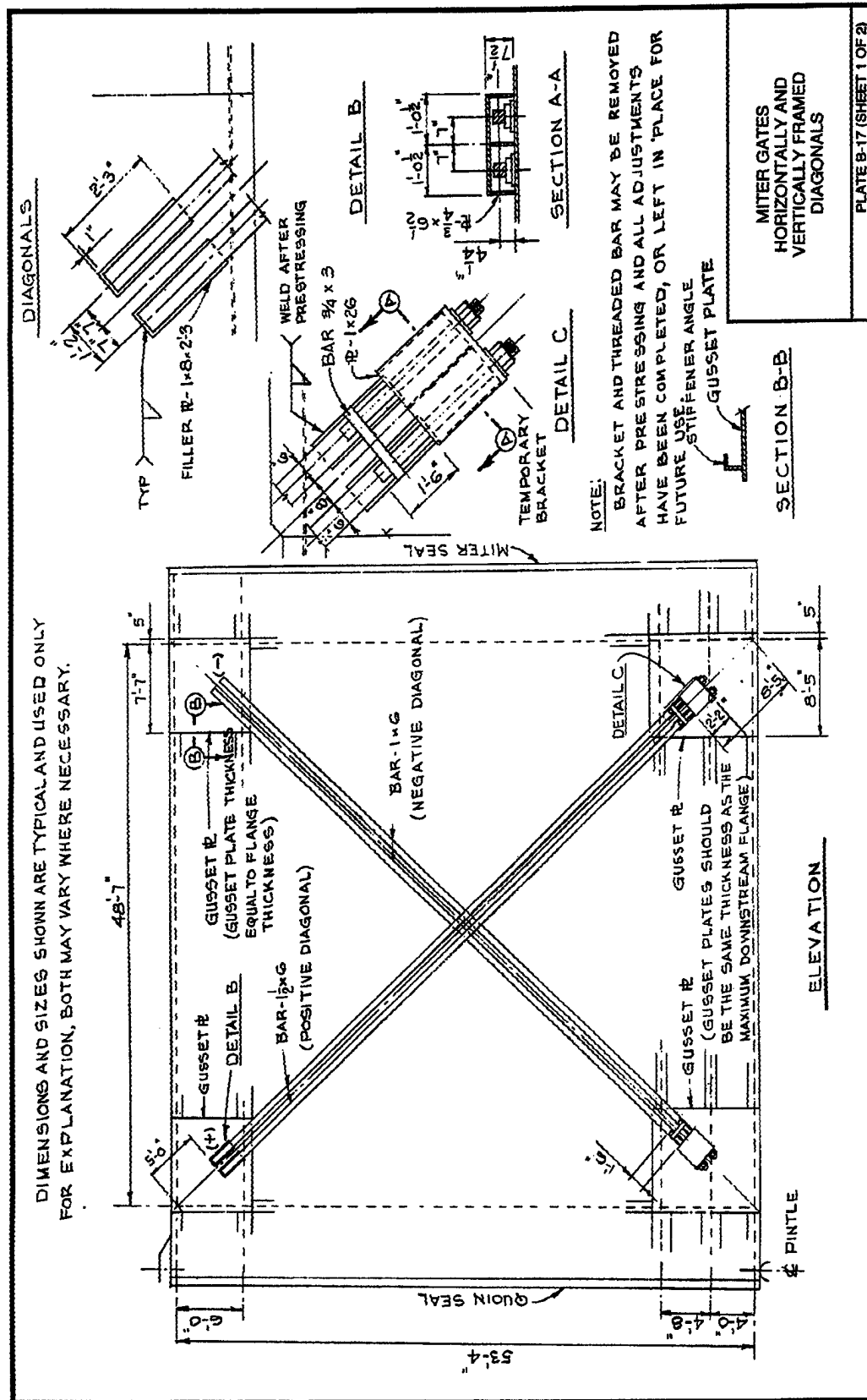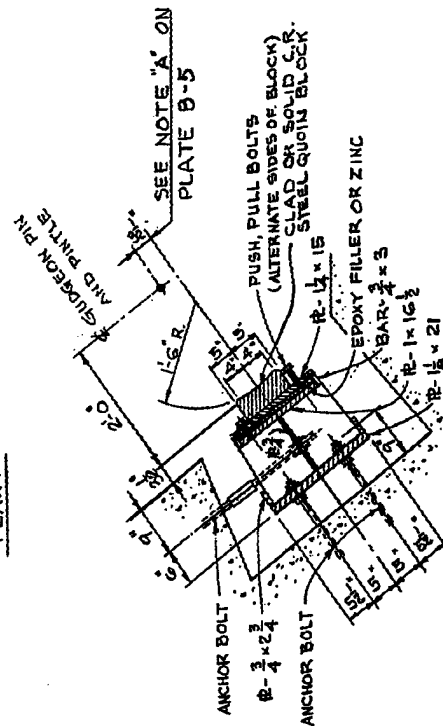
2'-½" R

1¾" TYP.

2" DIA. CORED HOLE (TYP)

3"   3"

PLAN

NOTE:
PINTLE BASE FOR VERTICALLY
FRAMED GATES SIMILAR TO
THE PINTLE BASE SHOWN.
SEE PLATE B-32 FOR
PLAN OF PINTLE BASE FOR
VERTICALLY FRAMED
GATE.

WEIGHT

$r = \sin \phi$

R H IS THE RESULTANT
OF R_a AND R_b (SEE PLATE B-8)

R H

R

r

φ

PINTLE

AREA OF ½ CIRCLE = $\dfrac{\pi D^2}{8}$

$I = 0.109757 \, R^4$

$m = 0.424413 \, R$

AREA OF ½ ELLIPSE = $\dfrac{\pi ab}{2}$

$I = ba^3 \left(\dfrac{\pi}{8} - \dfrac{8}{9\pi}\right)$

$n = 4a / 9\pi$

BEARING ON BUSHING = $\dfrac{R}{A} \pm \dfrac{Mc}{I}$

REF. AXIS

PROJECTED AREA

QUOIN SEAL

EPOXY OR ZINC FILLER

PINTLE SOCKET

GATE REACTION

PINTLE BUSHING

PINTLE

PINTLE SHOE

PINTLE BASE

SECTION THRU PINTLE ASSEMBLY

MITER GATES
HORIZONTALLY FRAMED
UPPER GATE
FLOATING PINTLE
ASSEMBLY

PLATE B-14

NOTES

1. DIMENSIONS AND DETAILS SHOWN ARE TYPICAL AND VARY AS REQUIRED BY GATE SIZE.

2. ANCHOR BOLTS TO BE PRESTRESSED TO THE MAXIMUM TENSILE LOAD PLUS 5 K.

3. ANCHOR UNITS ON LOWER END OF BOLTS TO BE DESIGNED FOR MAXIMUM LOAD, ASSUMING NO LOAD CARRIED BY BOND ON BOLTS.

SECTION A-A

PLAN

TOP ANCHORAGE ASSEMBLY

MITER GATES
HORIZONTALLY FRAMED
TOP ANCHORAGE
ASSEMBLY

NOTES
1. DIMENSIONS AND MATERIALS SHOWN ARE TYPICAL AND VARY AS REQUIRED BY GATE SIZE.

MITER GATES
HORIZONTALLY FRAMED
FIXED PINTLE
ASSEMBLY DETAILS

DIMENSIONS AND SIZES SHOWN ARE TYPICAL AND USED ONLY
FOR EXPLANATION, BOTH MAY VARY WHERE NECESSARY.

DIAGONALS

DETAIL B

SECTION A-A

BAR 3/4 x 3

FILLER R-1x8-2'3

WELD AFTER PRESTRESSING

TYP

DETAIL C

BAR-1x26

TEMPORARY BRACKET

MITER SEAL

NOTE:
BRACKET AND THREADED BAR MAY BE REMOVED
AFTER PRESTRESSING AND ALL ADJUSTMENTS
HAVE BEEN COMPLETED, OR LEFT IN PLACE FOR
FUTURE USE.

STIFFENER ANGLE

GUSSET PLATE

SECTION B-B

GUSSET R
(GUSSET PLATE THICKNESS
EQUAL TO FLANGE
THICKNESS)

BAR-1x6
(NEGATIVE DIAGONAL)

DETAIL C

GUSSET R

BAR-1½x6
(POSITIVE DIAGONAL)

DETAIL B

GUSSET R

GUSSET R
(GUSSET PLATES SHOULD
BE THE SAME THICKNESS AS THE
MAXIMUM DOWNSTREAM FLANGE)

PINTLE

QUOIN SEAL

ELEVATION

48'-7"

53'-4"

7'-7"

5'

5'

8'-5"

6'-0"

4'-8"

4'-0"

MITER GATES
HORIZONTALLY AND
VERTICALLY FRAMED
DIAGONALS

PLATE B-17 (SHEET 1 OF 2)

SECTION A-A

SECTION B-B

SECTION C-C

DIMENSIONS AND SIZES SHOWN ARE TYPICAL AND USED ONLY
FOR EXPLANATION, BOTH MAY VARY WHERE NECESSARY.

ELEVATION

PLAN OF GATES IN MITERED POSITION

(SHOWING CONVEX AND CONCAVE BLOCK)
MITERING GUIDE NOT SHOWN)

PLAN 1

PLAN 2

PLAN 3

SECTIONS THRU WALL QUOIN

MITER GATES
HORIZONTALLY FRAMED
QUOIN AND MITER
BLOCKS

PLATE B-18

WALKWAY AND MITER GUIDE

LOCK

SAFETY CHAIN

4'-0" OUT TO OUT ANGLES

GRATING $1\frac{1}{4}$, TYPE II

SUPPORT ANGLE

HINGE (WALKWAY)

STRUCTURAL TEE

GUDGEON PIN

HINGE (WALKWAY)

GUDGEON PIN

C 3×6

4'-5" R. TO BACK OF C

$\frac{19}{7\frac{5}{2}}$

GRATING, $1\frac{1}{4}$ TYPE II

PLAN OF WALKWAY

GUIDE BRACKET

$\frac{1}{2}$" EPOXY FILLER

END ℄

THRUST ℄

ROLLER BRACKET

STEEL SHIMS

FLANGE ℄

LEFT LEAF

RIGHT LEAF

MITER GUIDE ASSEMBLY

PIPE HANDRAIL

BULKHEAD ℄

STIFFENER BAR

STRUCTURAL TEE

SKIN ℄

TOP GIRDER

4'-0"
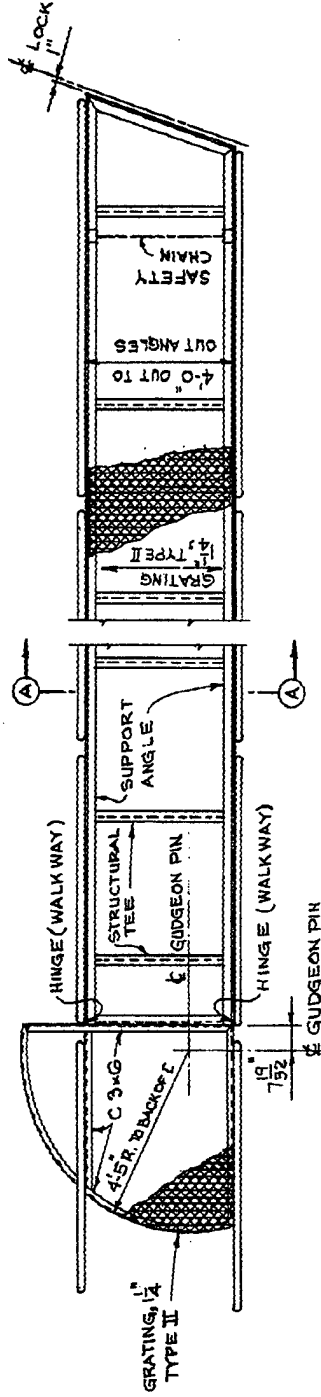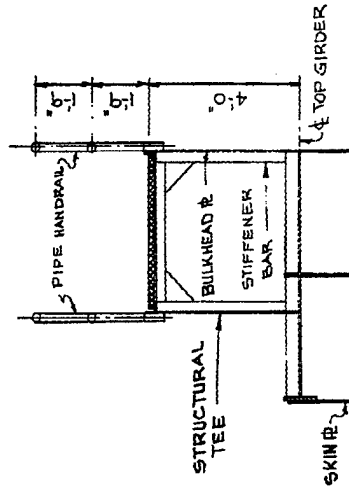
SECTION A-A
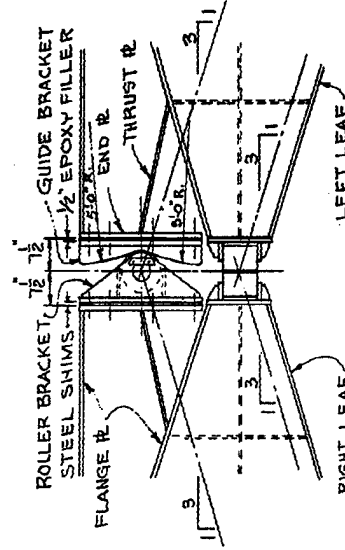
DIMENSIONS AND SIZES ARE TYPICAL AND USED ONLY FOR EXPLANATION, BOTH MAY VARY WHERE NECESSARY.

MITER GATES
HORIZONTALLY AND
VERTICALLY FRAMED
WALKWAY AND MITER
GUIDE

PLATE B-19

ROLLER BRACKET

U.S. FLG. PL.

A

1" RAISED WEB
(TYP.)

3'-0"

½" EPOXY FILLER

LOCK

3½"

3½"

3½"

3'-0"

3'-0"

LEFT LEAF

GUIDE BRACKET

RIGHT LEAF

PLAN OF MITERING DEVICE

WEB PL.

SPRING LINE

4
12

4
12

CURRENT

END DIAPHRAGM WEB

1'-0"

11½"

SECTION A-A

SILL ANGLE AND SEALS

DIMENSIONS AND SIZES ARE USED ONLY
FOR EXPLANATION, BOTH MAY VARY WHERE
NECESSARY.

THE ROUND SEAL IS NORMALLY MORE
ADVANTAGEOUS WHERE SUBSTANTIAL
TEMPERATURE CHANGES MAY OCCUR, CAUSING
THE LENGTH OF GATE LEAVES TO VARY.

FLOW

4" ROUND RUBBER
SEAL
PRESSURE HOLE
SECOND POUR
CONCRETE

ANCHOR BOLTS
SPACED ON APPROX.
1'-0" ALT. CTRS.

SECTION THRU SILL

"PORKCHOP"
RUBBER SEAL,
½" PRESET

FLOW

SECOND POUR
CONCRETE

ANCHOR BOLTS
SPACED ON APPROX.
1'-0" ALT. CTRS

SECTION THRU SILL

¢ LOCK

PINTLE

SILL ANGLE

RADIUS

¢ PINTLE TO
RADIUS POINT

SECOND POUR
CONCRETE

¢ PINTLE TO
RADIUS POINT

¢ PINTLE

RADIUS

PINTLE BASE

¢ PINTLE

MONOLITH
JOINT FILLER

OFFSET

THRUST LINE

PLAN OF SILL ANGLE

* SEE NOTE "A" ON PLATE B-5.

MITER GATES
HORIZONTALLY FRAMED
SILL ANGLE AND SEALS

PLATE B-21

SECTION THRU SILL

FLOW

SKIN PLATE

J - SEAL

H - BEAM

ANCHORS

SECOND POUR
CONCRETE

SECTION A-A

SILL ANGLE

SILL PLATE

NOTE:

1. DIMENSIONS AND DETAILS SHOWN ARE
TYPICAL AND VARY AS REQUIRED BY
GATE SIZE.

* SEE NOTE "A" ON PLATE B-5

MITER GATES
HORIZONTALLY FRAMED
SILL ANGLE AND SEAL

QUOIN AND MITER WATER SEALS

LEFT LEAF

MITER SEAL PLATE

BULKHEAD PLATE

ϕ LOCK $\frac{1}{2}$"

RIGHT LEAF

MITER SEAL

BRACKET

BULKHEAD PLATE

BRACKET TO BE ADJUSTED FOR $\frac{1}{2}$" COMPRESSION
IN MITER SEAL BEFORE WELDING TO BULKHEAD PLATE

PLAN

BULKHEAD PLATE

BULKHEAD PLATE

ϕ TOP GIRDER

ELEVATION OF MITER SEAL

W.P.

ϕ PINTLE

RADIUS

WORKING LINE

$\frac{1}{3}$

$\frac{1}{3}$

CONTACT POINT

PLAN

EDGE OF BULKHEAD ϕ

ϕ TOP GIRDER

ϕ GUDGEON PIN

ELEVATION OF QUOIN SEAL
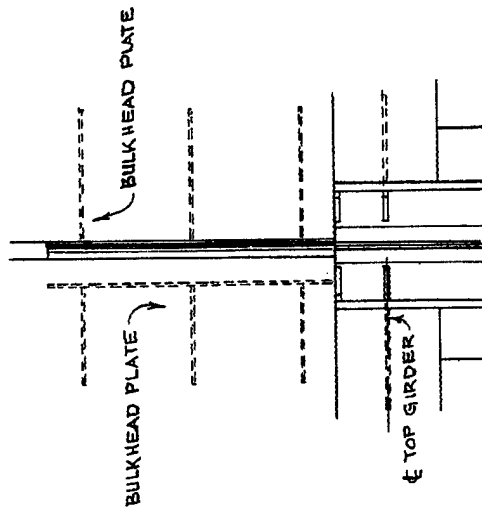
TIE BACK AND MITER LATCH

GATE RECESS

SLEEVE NUT

3'-9"

3'-6"

3

4

PLAN OF TIE BACK

DIMENSIONS SHOWN ARE TYPICAL
AND USED FOR CLARIFICATION ONLY.
DIMENSIONS MAY CHANGE WHERE
NECESSARY.

SAFETY CLIP

₵ TIE BACK

1"

₵ TOP GIRDER

SECTION B-B

FLOW

₵ LOCK

3'-6"

3'-6"

2'-6"

3

4

3

1

PLAN OF MITER LATCH

A   A

₵ LATCH

1"

₵ TOP GIRDER

SECTION A-A

MITER GATES
HORIZONTALLY AND
VERTICALLY FRAMED
GATE LATCHES

PLATE B-24

PLAN

LATCH HOOK

MITER GATE

ELEVATION
LATCHING DEVICE

TOP OF LOCK WALL

ANCHOR BOLTS

LIMIT SWITCH
SECOND POUR

LIMIT SWITCH

LATCH HOOK

TOP OF GIRDER

GATE CATCH

MITER GATES

FACE OF LOCK WALL

1¼"±

DIMENSIONS SHOWN ARE
TYPICAL AND USED FOR
CLARIFICATION ONLY.
DIMENSIONS MAY CHANGE
WHERE NECESSARY.

MITER GATES
HORIZONTALLY FRAMED
AUTOMATIC
LATCHING DEVICE

PLATE B-26

ARCH RIB DESIGN DATA

RIB NO.	DESIGN HEAD, ft	PRESSURE ksf	PRESSURE k/in ft	MAX THRUST	ECCENT in.	MOMENT kin.	GROSS AREA, sq in.	MAX STRESS ksi
1 to 15	107.5	6.72	17.34	945	0.35	331	67.06	14.69
16 to 22	82.0	5.13	14.75	804	0.54	434	61.54	14.04
23 to 27	60.5	3.78	12.76	696	1.45	1082	59.34	14.01
28 to 30	42.0	2.53	10.51	573	2.28	1306	55.x1	13.47
31 to 33	29.5	1.84	8.74	476	3.16	1506	53.35	13.40
34 to 36	20.0	1.25	5.97	326	2.74	893	35.97	13.20

37. Designed for operating loads; Max 25 ksi

Intersection of work line at contact point of miter blocks.

Gate stop.

End post

53'-6"

Drain hole

Intercostals

Skin ℞

Work line of arch rib.

End post

Pintle & Gudgeon
Gate quoin post & seal contact block

Wall quoin post & seal contact

Symmetrical about ℄ line of lock.

43'-0"

Face of lock wall.

℄ of Pintle & Gudgeon

60°

20°

30°

HORIZONTAL ARCH GIRDER

SCALE IN FEET
2 0 2 4 6

MITER GATES
HORIZONTALLY FRAMED
TYPICAL ARCH GIRDER

PLATE B-28

HORIZONTAL DIAPHRAGM

SCALE IN FEET
2 0 2 4 6

MITER GATES
HORIZONTALLY FRAMED
HORIZONTAL ARCH
DIAPHRAGM
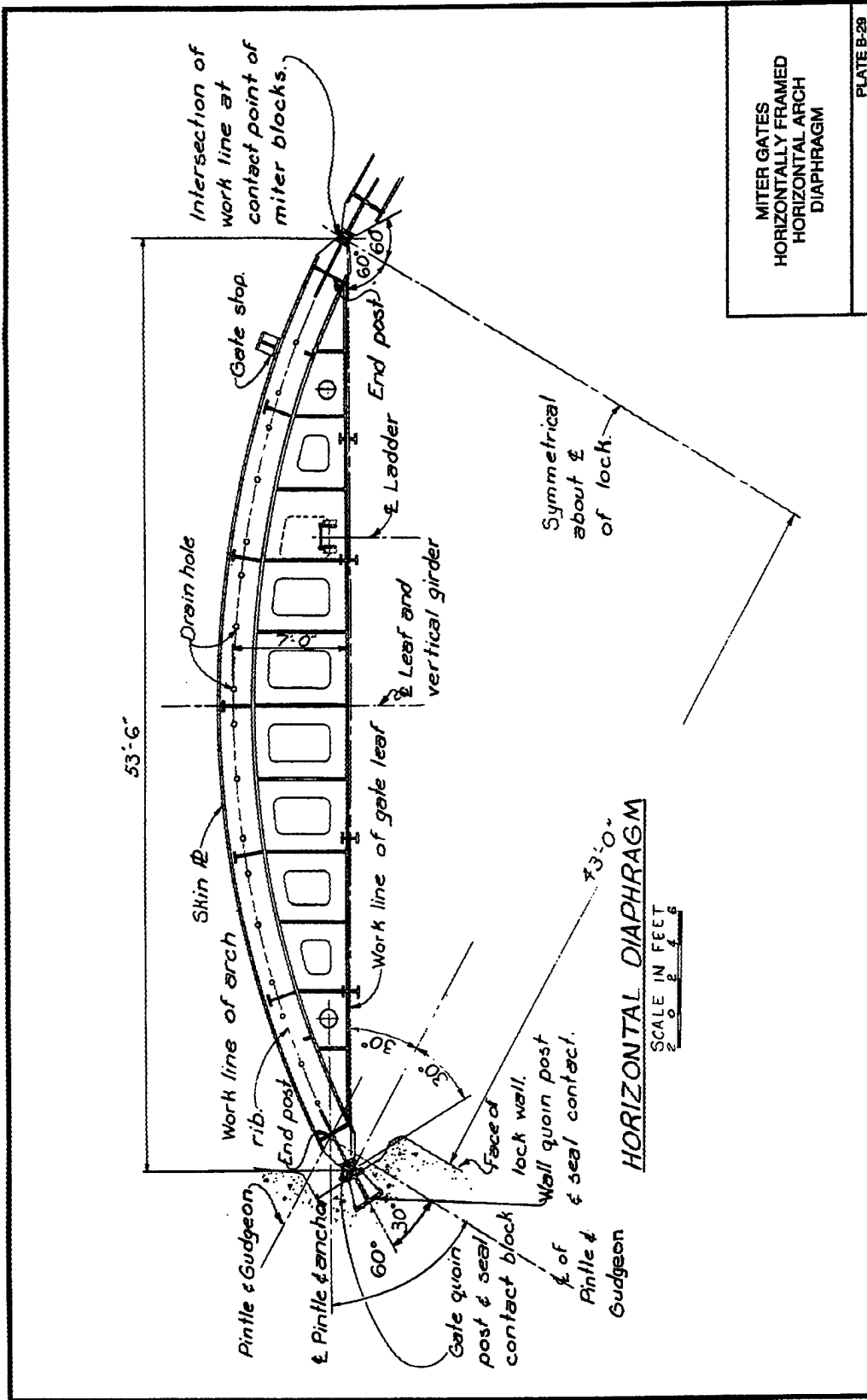
QUOIN BLOCK AND QUOIN WATER SEAL

VERTICALLY FRAMED GATE

SECTION B-B

THESE DETAILS ARE SHOWN AS AN
INDICATION OF THOSE ON EXISTING
STRUCTURES.

ADJUSTING
WEDGES
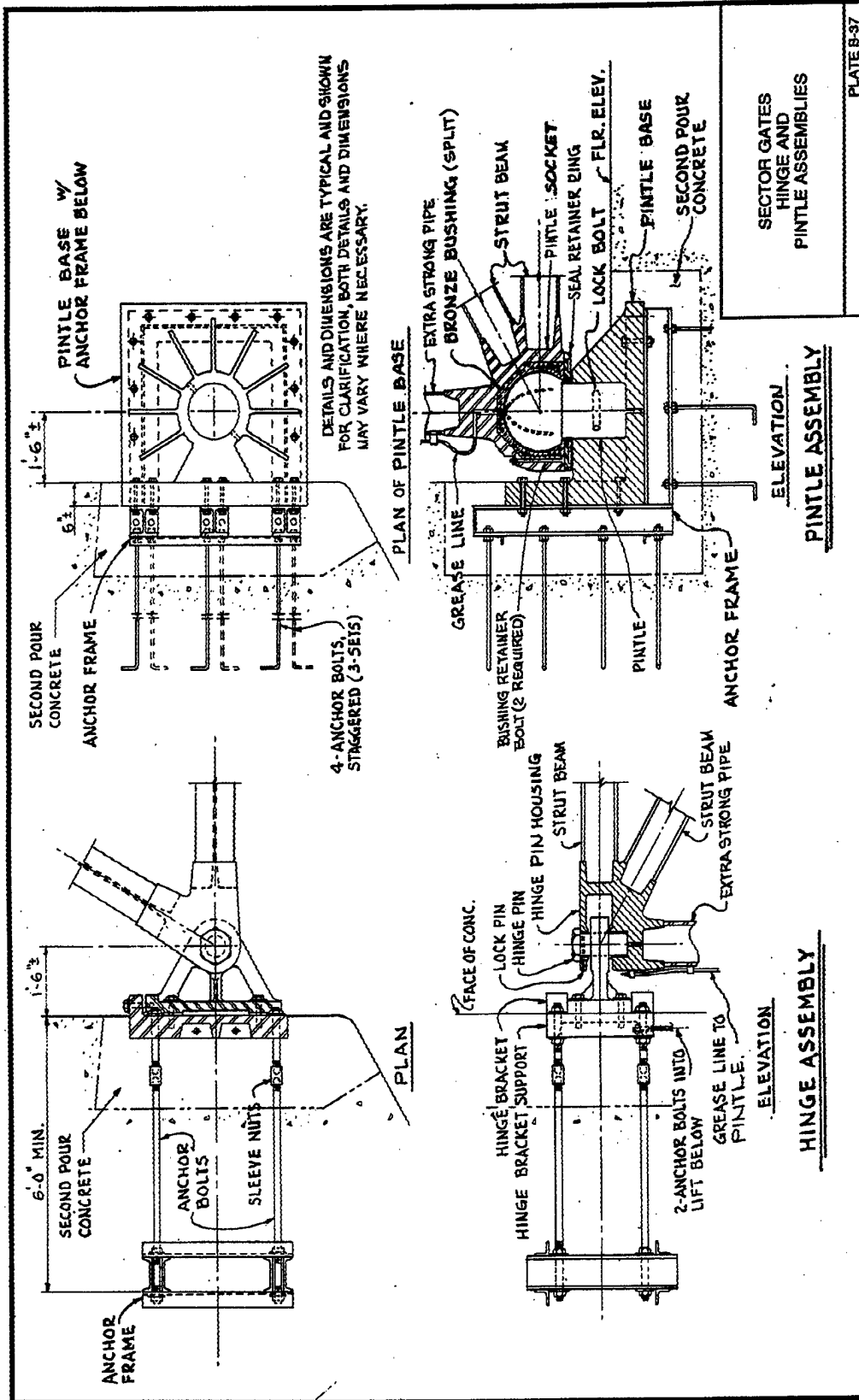
SECTION A-A

REACTION
BEAM

TOP OF SILL

BLOCK SEAL

SECTION C-C

SEAL

PINTLE BASE

℄ BOTTOM
GIRDER

SECTION D-D

PLAN OF QUOIN BLOCK

BLOCK SEAL

℄ SEAL
CHANNEL

PLAN OF QUOIN WATER SEAL

MITER GATES
VERTICALLY FRAMED
QUOIN BLOCKS AND
SEALS

PLATE B-30

MITER WATER SEALS
VERTICALLY FRAMED GATE

FLANGE

SEAL PLATE

RUBBER BLOCK

PLAN

ELEVATION

WATER STOP BELOW BOTTOM GIRDER

THESE DETAILS ARE SHOWN AS AN
INDICATION OF THOSE ON EXISTING
STRUCTURES

BOTTOM GIRDER
WEB

SEAL PLATE

SEAL

TYPICAL SECTION BELOW TOP GIRDER

BRACKET

SEAL
BRACKET

TYPICAL SECTION ABOVE TOP GIRDER

MITER GATES
VERTICALLY FRAMED
MITER SEALS

PLATE B-31

PINTLE AND SILL DETAIL
VERTICALLY FRAMED GATE

DIMENSIONS SHOWN ARE TYPICAL AND SHOWN FOR
CLARIFICATION ONLY. DIMENSIONS MAY CHANGE
WHERE NECESSARY.

STRUCTURAL TEE
SEAL PLATE

PLATE

REINF ROD

PLATE

SECOND POUR CONCRETE

ANCHOR BOLT

ANCHOR BOLT

1'-6"±

1'-4"±

SECTION A-A

SEAL PLATE

1
3

₵ LOCK

THESE DETAILS ARE SHOWN AS AN
INDICATION OF THOSE ON EXISTING
STRUCTURES.

₵ PINTLE

1
3

EDGE OF LOCK
WALL AND MONOLITH
JOINT

A

A

GROUT HOLE

HALF PLAN OF MITER SILL

₵ PINTLE

R-1'-2"

R

PINTLE BASE

OPERATING STRUT CONNECTION

NOTE:
DIMENSIONS SHOWN MAY VARY WHERE NECESSARY.

HORIZONTALLY FRAMED GATE AS SHOWN,
VERTICALLY FRAMED GATE SIMILAR.

OPERATING STRUT
CONNECTING

PLAN OF GIRDER

DIRECT ACTING CYLINDER TYPE CONNECTION

STRUT CONNECTION PLATE
FLANGE PLATE
TOP GIRDER
SKIN PLATE

VIEW D-D

℄ OPERATING STRUT CONNECTION

BULKHEAD PLATE
STIFFENER BAR
GUSSET PLATE
SKIN PLATE

SECTION E-E

GREASE LINE
STRUT PIN
℄ OPERATING STRUT
STIFFENER

SECTION C-C

BULKHEAD PLATE
℄ TOP GIRDER

SECTION B-B

STRUT TO ℄ PINTLE (VARIES)
℄ STRUT WITH GATE MITERED

1'-2 29/32"

℄ STRUT WITH GATE IN RECESS

BEARING COLLAR

BULKHEAD PLATE

PLAN AT ℄ OPERATING STRUT
HOOD TYPE CONNECTION

BEARING COLLAR
SPACE COLLAR AND RINGS
1" DIA HALF ROUND DRAIN HOLE
STRUCTURAL TEE
ANGLE SUPPORT (WALKWAY)

SECTION A-A

℄ TOP GIRDER TO
TOP OF GRATING

MITER GATES
HORIZONTALLY AND
VERTICALLY FRAMED
OPERATING STRUT
CONNECTIONS

PLATE B-33

SECTION B-B

WALKWAY

TIMBER FENDERS

HORIZONTAL GIRDER OR BEAM

VERTICAL RIB

WALKWAY ALL SIDES, ELEV.
TO SUIT TOP OF LOCK WALL

HINGE ASSEMBLY

PINTLE BASE

BOTTOM SEAL

SECTION A-A

(SHOWING VERTICAL TRUSS)

SIDE SEAL

VERTICAL BEAM

WALKWAY (ABOVE)

RECESS SIDE

HINGE ASSEMBLY

FACE OF LOCK WALL

WALKWAY

VERTICAL BEAM

SKIN PLATE

CONTACT SEAL

WALKWAY

VERTICAL BEAM

CHANNEL SIDE

TIMBER FENDERS AND SUPPORT MEMBERS

SYMMETRICAL ABOUT ₵ LOCK

PLAN

(SHOWING HORIZONTAL TRUSS)

SECTOR GATES
GENERAL PLAN
AND SECTIONS

PLATE B-34

TRUSS ELEVATION
(CHANNEL SIDE)

PLAN

NOTE: NUMEROUS EXISTING SECTOR GATES ARE FRAMED AS SHOWN. THIS TYPE OF FRAMING IS NOT RECOMMENDED FOR NEW CONSTRUCTION.

SECTOR GATES
GENERAL PLAN
AND ELEVATION

PLATE B-35

BOTTOM SEAL

SIDE PRESS SEAL

DETAIL "A"

TIMBER BUMPERS
ON RECESS SIDE OF GATE

PLAN

SEAL AT PINTLE

CENTER CONTACT SEAL

PINTLE BASE w/
ANCHOR FRAME BELOW

DETAILS AND DIMENSIONS ARE TYPICAL AND SHOWN
FOR CLARIFICATION, BOTH DETAILS AND DIMENSIONS
MAY VARY WHERE NECESSARY.

SECOND POUR
CONCRETE

ANCHOR FRAME

4-ANCHOR BOLTS,
STAGGERED (3-SETS)

PLAN OF PINTLE BASE

EXTRA STRONG PIPE
BRONZE BUSHING (SPLIT)
STRUT BEAM
PINTLE SOCKET
SEAL RETAINER RING
LOCK BOLT
FLR. ELEV.
PINTLE BASE
SECOND POUR
CONCRETE

GREASE LINE

BUSHING RETAINER
BOLT (2 REQUIRED)

PINTLE

ANCHOR FRAME

ELEVATION

PINTLE ASSEMBLY

SECOND POUR
CONCRETE

ANCHOR
BOLTS

SLEEVE NUTS

PLAN

ANCHOR
FRAME

FACE OF CONC.

LOCK PIN
HINGE PIN
HINGE PIN HOUSING
STRUT BEAM

STRUT BEAM
EXTRA STRONG PIPE

HINGE BRACKET
HINGE BRACKET SUPPORT

2-ANCHOR BOLTS INTO
LIFT BELOW

GREASE LINE TO
PINTLE

ELEVATION

HINGE ASSEMBLY

SECTOR GATES
HINGE AND
PINTLE ASSEMBLIES

SECTOR GATES
ALTERNATE HINGE AND
PINTLE ASSEMBLIES

EMERGENCY GATE
OPERATING
PROCEDURE

FLOW

REMOVABLE OVERFLOW NAPPE
WITH BOLTING COLLAR

SKIN PL.

DRUM TYPE SEAL

RUBBER SEALS
SIDES AND BOTTOM

SILL ELEV.

TRASH
SCREENS

DOWNSTREAM LEAF

UPSTREAM LEAF

TRASH
SCREENS

REACTION
WHEELS

CONC. RECESS

CONC. OR STEEL GATE
SUPPORT PEDESTAL

SHEAVE ASSEMBLY

SECTION B-B

TRASH SCREENS NOT SHOWN

TRASH SCREENS
TYP. PANEL

SECTION A-A (GENERAL ELEVATION)

FLOW

₵ CHANNEL

CABLE SHEAVE
ASSEMBLIES

SKIN PL.

DOWNSTREAM LEAF

UPSTREAM LEAF

SKIN PL.

GENERAL PLAN

VERTICAL-LIFT GATES
DOUBLE-LEAF
GENERAL PLAN
AND ELEVATION

PLATE B-40

SECTION A-A

SKIN PL.

SIDE SEAL

½ CLEAR

¾" CLEAR

½ CLEAR

GUIDE ASSEMBLY ON TOWER

SECTION C-C

ALL EMBEDDED GUIDE BMS. SHOULD BE ADJUSTABLE

¾" CLEAR

SEAL PL.

½" CLEAR ROLLER

½" CLEAR

ARMOR PL. ON RECESS

SECOND POUR, CONC. AROUND GATE RECESS

SECTION B-B

SIDE SEAL ASSEMBLY

℄ ROLLER

BOTTOM CONTINUOUS RUBBER SEAL

BOTTOM CORNER SEAL

DIMENSIONS AND DETAILS SHOWN MAY VARY WHERE NECESSARY

GENERAL ELEVATION

BRIDGE GIRDER

DOGGING PL.

GATE OVERRUN

GATE, BOTTOM, IN OPEN (DOGGED) POSITION

GATE, TOP IN CLOSED POSITION

Ⓐ

Ⓑ

Ⓒ

VERTICAL-LIFT GATES
SINGLE LEAF WITH TOWERS
GENERAL ELEVATION AND
TYPICAL DETAILS

PLATE B-41

SECTION A-A

HALF PLAN — LIFT GATE MONO. L-3

HALF DOWNSTREAM ELEVATION

DOGGING ℞

THE DOGGING DEVICE SHOWN IS FOR A TYPICAL SINGLE-LEAF GATE WITH A BRIDGE SPANNING BETWEEN TOWERS. DETAILS SHOWN ARE FOR INFORMATION AND MAY VARY WHERE NECESSARY.

GATE DOGGING DEVICE

EFFECTIVE RADIUS OF GYRATION $= \dfrac{(\ell_1 \times r_1)+(2\ell_2 \times r_2)+(2\ell_3 \times r_3)}{\ell_1 + 2\ell_2 + 2\ell_3}$

THE VALUES OF "r" FOR THE TAPERED SECTION SHOULD BE CONSIDERED AS THE AVERAGE OF THE MAXIMUM AND MINIMUM VALUE OF "r".
THE EFFECTIVE LENGTH SHOULD BE THE TOTAL LENGTH OF THE GIRDER, CENTER TO CENTER OF BEARING GIRDERS.

COLUMN AREA $A = (\ell_1 \times 1.0) + 2 \times \ell_2 \times \dfrac{It_1}{It_2}$

$\dfrac{I}{EI} = 1.0$ FOR CENTER OF ANALOGOUS COLUMN

$\dfrac{M}{EI}$ DIAGRAM

ANALOGOUS COLUMN LOAD IS EQUIVALENT TO THE VOLUME OF THE DIAGRAM SHOWN, USING PARABOLIC CURVES AS THE SHAPE OF THE DIAGRAM.

F.E.M. $= \dfrac{\text{COLUMN LOAD}}{\text{COLUMN AREA}}$

ACTUAL MOMENT = SIMPLE "M" MINUS F.E.M. (MID SPAN)

SKIN PLATE DESIGN DATA

VERTICAL-LIFT GATES
TYPICAL DESIGN DATA

WEIGHT

A

R_A

B

R_B

R_A AND R_B ARE REACTIONS
APPLIED TO BRACKETS

P

M

R_B

P_1 (VERTICAL SHEAR)(DIRECT)

SHEAR
(FROM MOMENT)

EFFECTIVE COLUMN
REPLACE R_B WITH P'AND M
(SYSTEM STILL HAS TO BE ADJUSTED
FOR DISTANCE TO C.G.)

MOMENT DIAGRAM

TEE (BOTH SIDES
OF END PLATE)

SKIN PLATE

END PLATE

BRACKET "B"

BRACKET "A"

VIEW A-A

A

A

P

BRACKET "B"

BRACKET "A"

ISOMETRIC

ELEVATION

SECTIONAL ELEVATION

2' 0   2' 4' 6'

TAINTER GATES
SUBMERGIBLE TYPE
TYPICAL END FRAME
AND CROSS SECTION

PLATE B-45

Side Seal

Skin

Plate girder

Blockout

Trunnion

₵ Trunnion

Anchor Studs

₵ Trunnion

SECTIONAL PLAN A

SECTION B-B

SECTION A-A

PLAN

GATE MACHINERY
MITER GATE
PANAMA TYPE
MACHINE ASSEMBLY

PLATE B-47

KEY PLAN

SECTION A-A

PLAN

SECTION B-B

DETAIL A
ALTERNATE LIMIT SWITCH ARRG'T

SECTION A-A
ASSEMBLY OF SPRING-TYPE STRUT

STRUT END DETAIL MAY VARY DEPENDING
ON TYPE OF SECTOR ARMS USED

DIMENSIONED SHOWN ARE FOR ILLUSTRATION
AND MAY VARY WHERE NECESSARY

LUBE FITTING

SECTIONAL PLAN

SEE EM STAGE OF FOUR (4) PARALLEL
BELLVILLE (DISC) SPRING

LUBE FITTING

19'-8 17/64"

ELEVATION
MITER GATE STRUT ASSEMBLY
SCALE 1 1/2" = 1'-0"

LUBE FITTING

SECTIONAL ELEVATION

STRUT SPRING ASSEMBLY

GATE MACHINERY
MITER GATE
BELLEVILLE (DISK) SPRING -
TYPE GATE STRUT
SPRING ASSEMBLY

PLATE B-53

SECTION B-B

Motor

Gear Reducer

GATE MACHINERY
SECTOR GATE
GEAR-TYPE
DRIVE MACHINE

PLATE B-54

Lighting standard

Brake

Motor

Limit
Switch

Current

Face of Lock Wall

Special
Gears

Identification

Face of Gate Recess

Rack Teeth

Top of Lock Wall

L.S & Drive

PLAN

SECTION A-A

PLAN
(GATE IN OPEN POSITION)

PLAN
(GATE IN CLOSED POSITION)

SECTION A-A

SECTION B-B

GATE MACHINERY
SECTOR GATE
CABLE-TYPE
DRIVE MACHINE

PLATE B-55

SECTION A-A

HOIST SYSTEMS ELEVATION (TYP.)

ELEVATION (TYP.)

GATE MACHINERY
MULTILEAF
VERTICAL-LIFT GATES
ELEVATION-HOIST
MECHANISM

PLATE 8-56

LIST OF PARTS NOT DETAILED

MARK NO.	NO. REQ'D	DESCRIPTION	MATERIAL
M630/2-1	3	PARALLEL SHAFT REDUCER—SIMILAR AND EQUAL TO PHILADELPHIA CAM CORP. CLASS I SIZE 210HPL. #3 MOUNTED HORIZ. WITH EXTENDED SHAFT TO M630/2-7. AS REQUIRED.	CONN. GRADE
M630/2-2	3	PARALLEL SHAFT REDUCER—SIMILAR AND EQUAL TO PHILADELPHIA CAM CORP. CL. ONE SIZE 210HPL. #3 MOUNTED HORIZ. WITH EXTENDED SHAFT TO M630/2-7, AS REQUIRED.	CONN. GRADE
M630/2-3	6	FLEXIBLE COUPLING—SIMILAR AND AND EQUAL TO "FALK" TYPE G20, SERIES 1060G.	CONN. GRADE
M630/2-4	8	FLEXIBLE COUPLING—SIMILAR AND AND EQUAL TO "FALK" TYPE G20, SERIES 1060C.	CONN. GRADE
M630/2-5	3	ELECTRIC MOTOR—TEMP. 460—1200 RPM ADJUSTABLE 390 VOLT D.C. —SIMILAR AND EQUAL TO NORTHWESTERN ELECTRIC FRAME NO. 506AT.	CONN. GRADE
M630/2-6	3	ELECTRIC MOTOR—10HP, 460—1200 RPM ADJUSTABLE 390 VOLT D.C. —SIMILAR AND EQUAL TO NORTHWESTERN ELECTRIC FRAME NO. 506AT.	CONN. GRADE
M630/2-7	6	HOLDING BRAKE, 500—1000 FT—LB, —SIMILAR AND EQUAL TO "BEHR—OUTLER MAGNET" TYPE OHB6A, SIZE 16.	CONN. GRADE
M630/2-8	12	PILLOW BLOCK—SIMILAR AND EQUAL TO "DODGE" BEARING, FIXED TYPE, WITH LOCKNUT HOUSING AND LOCKPLATE PBB.	CONN. GRADE
M630/2-9	12	PILLOW BLOCK—SIMILAR AND EQUAL TO "DODGE" BEARING, FLOAT TYPE, WITH LOCKNUT HOUSING AND LOCKPLATE PBB.	CONN. GRADE
M630/2-10	22	TUBING—RECTANGULAR 2 X 3 X 0.12 X 1'—7" LONG.	ASTM A511 GR. WCBA
M630/2-11	4	BAR 1/2 x 4 x 4'—0"	METAL HARD TYPE 304
M630/2-12	4	L—8 X 3/4 X X X 0'—X"	ASTM A36
M630/2-13	44	HEX. HD. CAPSCREW—X'—13UNC—3A X 6 LONG WITH NUT AND LOCKWASHER	GEN A191 GR. B8 ...

SECTION A-A
SCALE: 3/4"=1'-0"

PLAN @ ELEVATION 395.0'
SCALE: 3/4"=1'-0"

ELEVATION D-D

SECTION C-C

SECTION B-B

ROPE REEVING DIAGRAM

SECTION E-E

GATE MACHINERY
VERTICAL-LIFT GATES
HOISTING MECHANISM
SECTIONS

GATE MACHINERY
VERTICAL-LIFT GATES
HOISTING MECHANISM
ELEVATION

GATE MACHINERY
TAINTER-TYPE GATES
HOISTING MECHANISM

PLATE B-60

GATE MACHINERY
HYDRAULIC SYSTEM
SCHEMATIC
CONSTANT DISPLACEMENT
PUMPS
MANUALLY OPERATED

PLATE B-61

GATE MACHINERY
HYDRAULIC SYSTEM
SCHEMATIC
VARIABLE DISPLACEMENT
PUMPS
SOLENOID OPERATED

LOCK GATES AND OPERATING
EQUIPMENT GATE MACHINERY
VARIABLE DISPLACEMENT PUMPS
SOLENOID PILOT OPERATED
FOR INUNDATED LOCKS
HYDRAULIC SYSTEM SCHEMATIC

PLATE B-63

LOCK GATES AND
OPERATING EQUIPMENT
ELECTRICAL SYSTEMS
SINGLE LINE DIAGRAM

PLATE B-64

ANNUNCIATOR SYSTEM

CULVERT VALVE SELSYN CONTROL

AUTOMATIC LUBRICATION CABINET

DOWNSTREAM LEFT GATE LUB SYSTEM
(OTHER 3 GATES LUB SYSTEM SIMILAR)

NAVIGATIONAL SIGNAL LIGHT CONTROL

AIR HORN

BUBBLER CONTROL

UPSTREAM

DOWNSTREAM

UPSTREAM NAVIGATIONAL SIGNAL LIGHT SELECTOR PUSH BUTTON

BACK-UP/NORMAL TRANSFER SWITCH

LOCK GATES AND
OPERATING EQUIPMENT
ELECTRICAL SYSTEMS
CONTROL SCHEMATICS

PLATE B-66 (SHEET 1 OF 5)

LOCK GATES AND
OPERATING EQUIPMENT
ELECTRICAL SYSTEMS
VALVE/GATE CONTROL
SCHEMATIC

LOCK GATES AND
OPERATING EQUIPMENT
ELECTRICAL SYSTEMS
VALVE/GATE CONTROL
SCHEMATIC

LOCK GATES AND
OPERATING EQUIPMENT
ELECTRICAL SYSTEMS
VALVE/GATE CONTROL
SCHEMATIC

LEFT WALL HYDRAULIC PUMPING RATE CONTROL (OIL PUMP NO. 2)

RIGHT WALL HYDRAULIC PUMPING RATE CONTROL (OIL PUMP NO. 1)

LOCK GATES AND
OPERATING EQUIPMENT
ELECTRICAL SYSTEMS
VALVE/GATE CONTROL
SCHEMATIC

PLATE B-66 (SHEET 4 OF 5)

LOCK GATES AND
OPERATING EQUIPMENT
ELECTRICAL SYSTEMS
VALVE/GATE CONTROL
SCHEMATIC

PLATE B-66 (SHEET 5 OF 5)

UPPER MITER GATE (DOWNSTREAM ELEVATION)
SCALE 1/4"=1'-0"

LOWER MITER GATE (DOWNSTREAM ELEVATION)
SCALE 1/4"=1'-0"

SECTION A-A
SCALE NONE

LOCK GATES
ELECTRICAL SYSTEMS
GATE LIMIT SWITCH
LOCATION

PLATE B-67 (SHEET 1 OF 2)

SECTION A-A
SCALE: ⅜"=1'-0"

UPPER GATE PLAN
SCALE: ⅜"=1'-0"

SECTION B-B
SCALE: ⅜"=1'-0"

FLOW

LOCK GATES
ELECTRICAL SYSTEMS
GATE LIMIT SWITCH
LOCATION
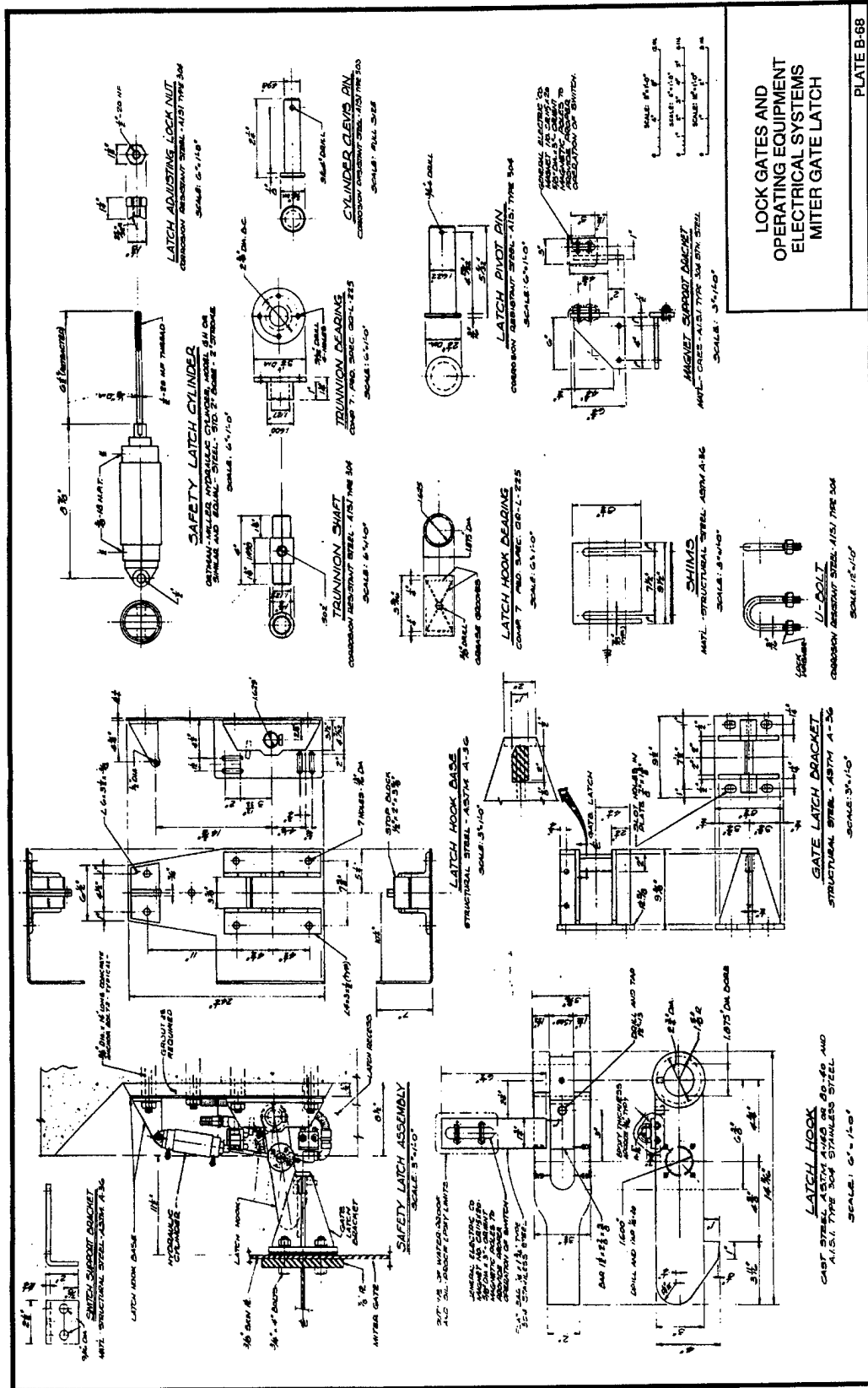
LOCK GATES AND
OPERATING EQUIPMENT
ELECTRICAL SYSTEMS
MITER GATE LATCH
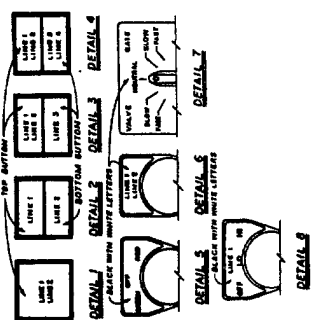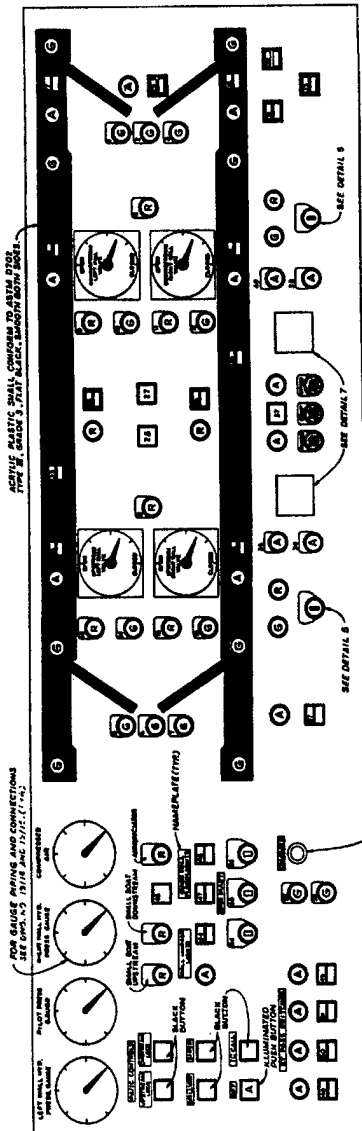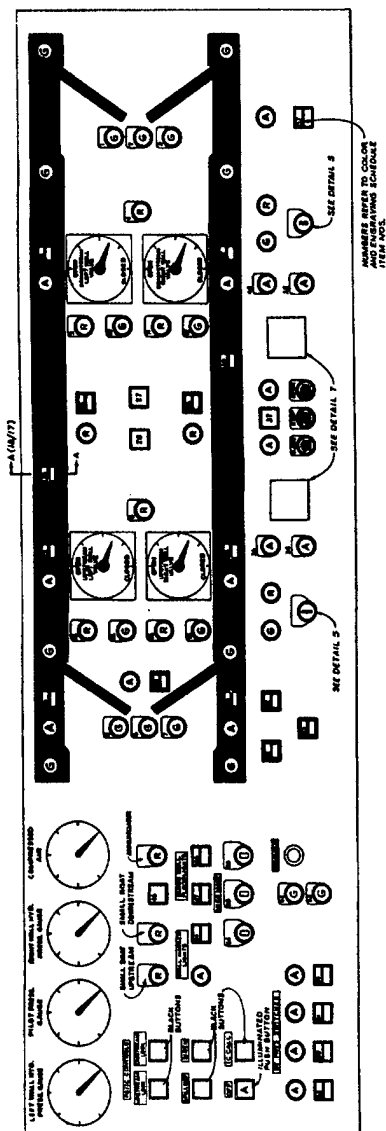
LOCK GATES AND
OPERATING EQUIPMENT
ELECTRICAL SYSTEMS
CONTROL CONSOLE
LAYOUT

LOCK GATES AND
OPERATING EQUIPMENT
ELECTRICAL SYSTEMS
BACKUP CONTROL
CONSOLE

PLATE B-70

MITER GATE NO. 3

MITER GATE NO. 4

MITER GATE NO. 1

MITER GATE NO. 2

LEGEND

CS   MITER GATE CONTROL SWITCH
CC1   CLOSE CONTACTOR
OC1   OPEN CONTACTOR
O.L.   MOTOR OVERLOAD
#2   SPLIT TORQUE LIMIT SWITCH
#3   LOCAL-REMOTE PERMISSIVE SWITCH
        PERMISSIVE SWITCH LOWER BOOTH
        PERMISSIVE SWITCH UPPER BOOTH
TR2   ALARM RELAY - COMPLETION
TR1   ALARM RELAY - TENSION

MITER GATE CONTROL SWITCH
Spring Return to Off.

MITER GATE LIMIT SWITCH

STRUT STRESS LIMIT SWITCH

LOCK GATES
ELECTRICAL SYSTEMS
CONTROL SCHEMATIC
MITER GATES
SINGLE-SPEED MOTOR

PLATE B-71

LOCK GATES
ELECTRICAL SYSTEMS
CONTROL SCHEMATIC
MITER GATES
TWO-SPEED MOTOR

PLATE B-72

LOCK GATES
VERTICAL-LIFT GATE
ELECTRICAL SYSTEMS
CONTROL SCHEMATIC
EMERGENCY TYPE

PLATE B-73

LOCK GATES
TAINTER TYPE
CONTROL DIAGRAM

NOTES:

GUIDE PLAN
LOCK CATHODIC
PROTECTION
UPPER MITER GATE
UPSTREAM ELEVATION

(SHEET I-1)

PLATE B-75

UPSTREAM ELEVATION

SECTION "A-A"

NOTES:

GUIDE PLAN
LOCK CATHODIC
PROTECTION
UPPER MITER GATE
DOWNSTREAM ELEVATION

(SHEET I-2)

PLATE B-76

6" DIA. BUTTON ANODE – TYPE "A"

DETAIL "I"
TYPICAL ANODE ASSEMBLY

SECTION X-X

DETAIL "D"
6" DIA BUTTON ANODE
NOT TO SCALE

PLAN

SECTION A-A'

DETAIL "F"
BUTTON ANODE CABLING PROTECTION

TYPICAL SIDE VIEW

DETAIL "J"
WATERTIGHT CONDUIT GIRDER PENETRATION
NO SCALE

DETAIL "E"
CABLE SUSPENSION
NOT TO SCALE

DETAIL "C"
CONDUIT CLAMP
NTS

DETAIL "G"
WATERTIGHT GLAND
NO SCALE

GUIDE PLAN
LOCK CATHODIC
PROTECTION
DETAILS

PLATE B-77

(SHEET I-5)

SIDE VIEW

REAR VIEW

RECTIFIER CABINET
NOT TO SCALE
(TYPICAL)

CLAMP

RECTIFIER

LOCK WALL DECK

SEE NOTE

NOTE:
ALWAYS CLAMP MOUNTING LOCATION ON RECTIFIER CABINET AS REQUIRED TO FIT HEIGHT ABOVE OF THE LOCK WALL DECK OF THE LOWER MEMBER OF THE HANDRAIL.

TO STRING ANODES

Common to GATE STEEL

(+) (−) (+)

TO BUTTON ANODES

SELENIUM FULL BRIDGE RECTIFIER

Secondary Taps

FINE TAPS / COARSE TAPS

TYPICAL RECTIFIER SCHEMATIC WIRING DIAGRAM
NOT TO SCALE

NOTE: TWO SEPARATE TRANSFORMERS OR ONE TRANSFORMER WITH TWO SECONDARY WINDINGS MAY BE UTILIZED IN LIEU OF ABOVE. TYPICAL IF TWO TRANSFORMERS ARE USED, ONE CIRCUIT SHALL HAVE ITS OWN BREAKER, ANODE, AND CLAMP TO PROVIDE INDIVIDUAL READINGS OF EITHER THE STRING ANODE CIRCUIT OR THE BUTTON ANODE CIRCUIT, READINGS MAY BE USED IN LIEU OF TWO OF EACH METER AS SHOWN ABOVE.

SECOND RECTIFIER CIRCUIT. IF ONE CIRCUIT IS SPECIFIED, BUTTON ANODES AND STRING ANODES SHALL BE ON SAME CIRCUIT.

120 V, 1 PHASE, 60 Hz, A.C. INPUT

3/C #10 TYPE "SO" CORD

SURGE ARRESTER

SINGLE CONVENIENCE OUTLET MTD ON PANEL (GFI)

STEPDOWN TRANSFORMER

DETAIL "C"
CONDUIT GIRDER PENETRATION FOR STRING ANODES
NOT TO SCALE

3" PVC PROTECTIVE PIPE SCHEDULE 80

3" PVC COUPLING

CONDUIT JOINTS LOCATED AT GIRDER WHEN POSSIBLE

1/2" GIRDER PLATE

REINFORCING COLLAR 4" DIA., PIPE STANDARD STEEL

3-1/2" 1 1-1/2" 1 3/4" AWG (WHERE REQUIRED BY PLAN DIMENSION)

ANODE LEAD WIRE

SECTION "A−A"

TYPICAL ELECTRICAL CONNECTION AT TOP OF GATE
N.T.S.

GATE

LOCK WALL

TERMINAL BOXES

1" GS CONDUIT

3/C #10 TYPE SO CORD

STRING ANODE (TYPICAL)

STRING ANODE (TYPICAL)

METER END

QUOIN END

END Diaphragm

SECTION "B − B"

NOTE: SECTION "A−A" IS PROVIDED IN ORDER TO SHOW THE LOCATION OF THE BUTTON AND STRING ANODES ON THE LOWER GATE. THE LOCATION OF THE BUTTON ANODES TO BE INSTALLED ON THE UNDERSIDE OF THE BOTTOM GIRDER ARE NOT SHOWN ON THIS SECTION NOTE. REFER TO DRAWING I-1 FOR TYPICAL LOCATIONS.

(SHEET I-7)

GUIDE PLAN
LOCK CATHODIC
PROTECTION
DETAILS

PLATE B-78

EFFECTIVE MOMENT ARMS IN FEET

POS.	"A"	"B"
0	19.71	6.16
0.1	19.68	6.46
0.5	19.64	7.57
1.0	19.70	8.73
2.0	19.91	10.48
3.0	20.00	11.47
4.0	19.67	11.62
5.0	18.76	10.80
6.0	16.99	8.63
6.5	15.59	6.70
6.9	13.93	4.19
7.0	13.32	3.20

KINEMATICS
OHIO RIVER TYPE LINKAGE

PLATE B-79
(SHEET 1 OF 12)

EL. 145.0 (MAX.)

EL. 115.25 NORMAL
OPERATION
82% OF TIME

EL. 93.23

EL. 90.72

SILL

$2'-6\frac{1}{8}''$

ALL INFORMATION
IS THE SAME AS THAT FOR
ALICEVILLE LOCK
AND DAM

OPENING OPERATION (NORMAL OPERATION 82% TIME)

OPENING TIME 90 SEC ($1\frac{1}{2}$ MIN)
UNDERGATE CLEARANCE = $2'-6\frac{1}{8}''$
SUBMG (ASSUMED) = 22 FT

CYLINDER DIAM = 12" I.D.

ROD DIAM. = 5.0'   * TECHNICAL REPORT

STROKE = 12' $8\frac{5}{8}''$ NO. 2-651, JUNE '64,

OHIO TYPE LINKAGE

NOMENCLATURE		WES MODEL		PROPOSED LOCK ALICEVILLE		FACTOR	
LENGTH GATE	—	3.0	L_1	60.0 FT	$\frac{L_1}{L}$	= 20	
SUB MG	S / S_2	2.0 * (SEE PLATE B-64) / 40.0	S_1	22.0	$\frac{S_1}{S_2}$	= 0.55	
TIME	T / T_2	20.1 SEC'S * (SEE PLATE B-64) / 90.0 SEC	T_1	90.0			
ARC OF TRAVEL GATE	K	71.567	K_1	71.565	$\frac{T_2}{T_A}$	$= \frac{90}{90}$	

FACTOR $L_1 \div L = 60 \div 3 = 20$
S_1 = SUB. = 22 FT $S_2 = S (L_1 \div L) = 2 \times 20 = 40$
T_1 = 90 SEC ADJ. $T_2 = T \sqrt{L_1/L} = 20.1\sqrt{20} = 20.1 \times 4.47 = 90$

ANGULAR TRAVEL $TA = T_1\left(\frac{K}{K_1}\right)' = 90\left(\frac{71.565}{71.565}\right) = 90$

FACTOR $\frac{T_2}{TA} = \frac{90}{90} = 1$

$P_1 = P_0\left(\frac{L_1}{L}\right)^4\left(\frac{S_1}{S_2}\right)^{2.1}\left(\frac{T_2}{TA}\right)^{1.0} \times$ BOTTOM EFFECT FACTOR

$= P\ (20)^4(0.55)^{2.1}\left(\frac{90}{90}\right)^{1.0} \times 1.23 = P \times 160,000 \times 0.285 \times 1 \times 1.23$

$= P \times 45,600 \times 1.23$

$= P \times 56,100$

EFFECT OF BOTTOM CLEARANCE SEE PLATE 52
OF REPORT 2-651 OPEN'G CYCLE - INCREASE TORQUE
23% FACTOR 1.23, CLOSING CYCLE - INCREASE TORQUE
27% FACTOR 1.27

AVAILABLE TORQUE BASED ON 900-PSI NET CYL. PRESS.

RELATIVE EFFECT OF
GATE BOTTOM CLEARANCE
ON TORQUE
4.0-FT SUBMERGENCE

PLATE B-79
(SHEET 4 OF 12)

SUBMERGENCE - AS SHOWN IN FEET
CHAMBER LENGTH
    UPSTREAM - 25 FT
    DOWNSTREAM - 25 FT
BOTTOM CLEARANCE 0.25 FT

OHIO RIVER LINKAGE
EFFECT OF SUBMERGENCE
ON INSTANTANEOUS TORQUE
OPERATING TIME, 20.1 SEC

PLATE B-79
(SHEET 5 OF 12)

OPENING OPERATION

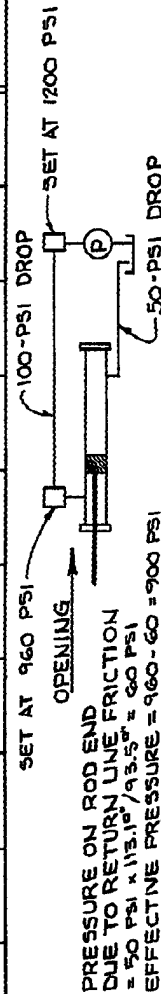|		REQUIRED LOADS								AVAILABLE TORQUE					
①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	⑫	⑬	⑭	⑰
WES TORQUE ABOUT PINTLE	CORR. FACTOR	TORQUE ABOUT PINTLE (ALICE-VILLE)	EFFECT. ARM ABOUT PINTLE	FORCE IN STRUT	EFFECT. ARM ABOUT SECTOR	TORQUE ABOUT SECTOR (0.95 EFF.)	SECTOR GEAR RADIUS	FORCE ON PISTON (0.95 EFF.)	CYL PRESS. (93.5")	CYL PRESS. (93.5")	FORCE ON PISTON (0.95 EFF.)	TORQUE ABOUT SECTOR (0.95 EFF.)	FORCE IN STRUT	TORQUE ABOUT PINTLE
LB-FT		③=①x② LB-FT	FT	⑤=③/④x1000 KIPS	FT	⑦=⑤x⑥/0.95 FT-KIPS	FT	⑨=⑦/⑥x0.95 KIPS	⑩=⑨x1000/93.5 +60 loss PSI	PSI	⑫=⑪x93.5/1000 x0.95 KIPS	⑬=⑫x⑥x0.95 FT-KIPS	⑭=⑬/④ KIPS	⑰=⑭x④ FT-KIPS
POSITION	56x10³													
0	2.2	123,000	19.71	6.2	6.16	40.	5.0	8.4	150	900	79.9	379.5	61.6	1210
0.5	2.2	123,000	19.64	6.3	7.57	50.		10.5	170				50.1	980
1	2.2	123,000	19.10	6.2	8.13	57.		12.0	190				43.5	860
2	2.2	123,000	19.91	6.2	10.48	68.		14.3	210				36.2	720.
3	3.0	168,000	20.00	8.4	11.47	101.		21.3	290				33.1	660
4	4.5	250,000	19.67	12.7	11.62	155.		32.6	410				32.7	640
5	6.0	340,000	18.76	18.1	10.80	206.		43.4	520				35.1	660
6	6.0	340,000	16.99	20.	8.63	182.		38.3	470				44.0	750
6.5	6.7	380,000	15.59	24.	6.70	169.		35.6	440				56.6	880
6.9	12.0	670,000	13.93	48.	4.19	212.		44.6	540				90.6	1260
7	0	0	15.32	0	3.20	0		0	0				119.0	1590

SET AT 960 PSI

OPENING →

PRESSURE ON ROD END
DUE TO RETURN LINE FRICTION
= 50 PSI x 113.1"/93.5" = 60 PSI
EFFECTIVE PRESSURE = 960-60 = 900 PSI

100-PSI DROP
SET AT 1200 PSI
50-PSI DROP
P

OHIO RIVER LINKAGE
MITER GATE MACHINERY
OPERATING DATA
OPENING

PLATE B-79 (SHEET 6 OF 12)

OHIO RIVER LINKAGE
GATE TORQUE ABOUT PINTLE
OPENING TIME
1.5 MIN
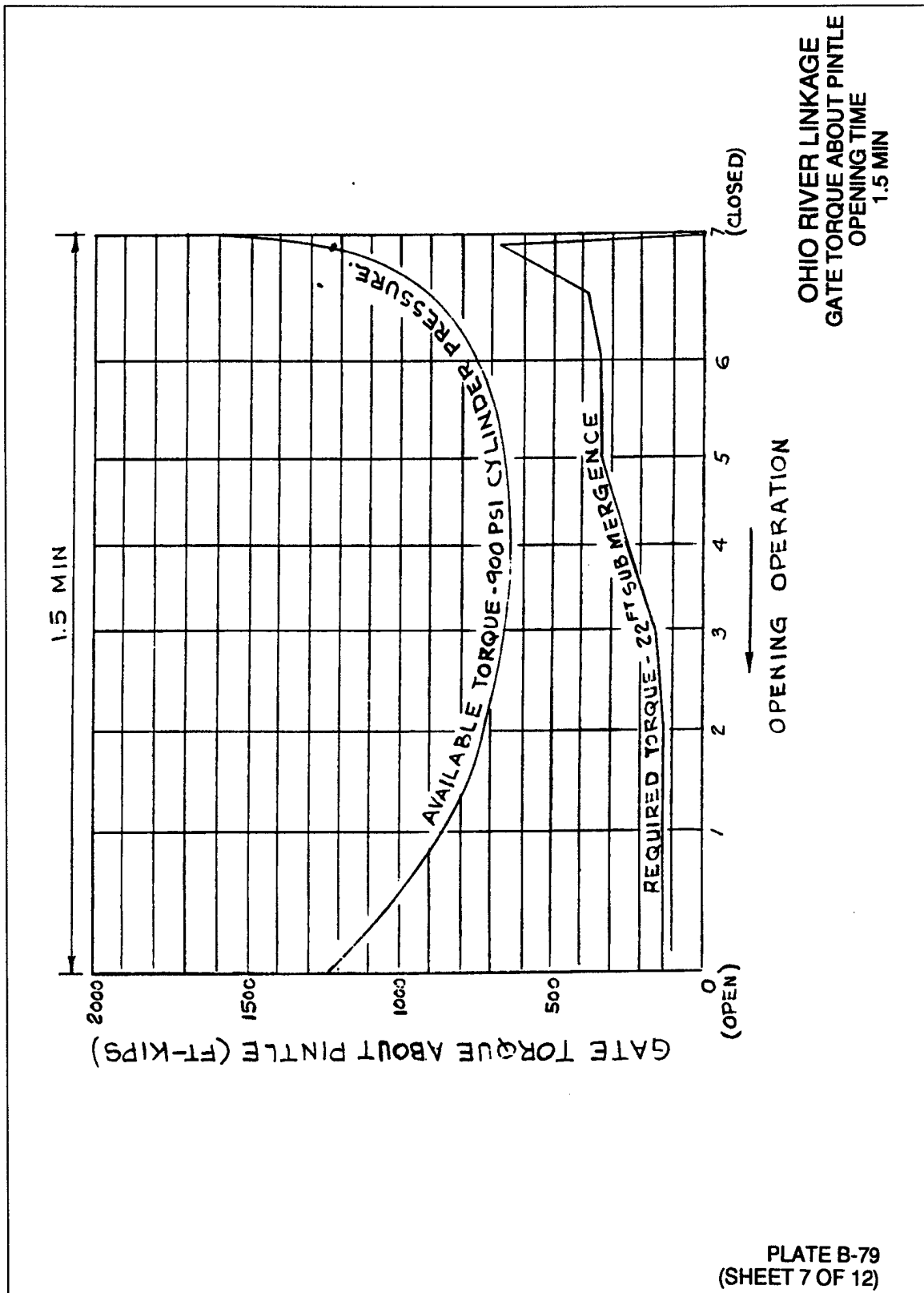
OPENING TIME = 1.5 MIN (ASSUMED)

$$\text{FLOW RATE} = \frac{(12^2 - 5^2)\, 0.7854 \times 12 \times 12.7234}{231 \times 1.5\,(MIN)} = 41.2\ \text{GPM}$$

$$\text{CLOSING TIME} = \frac{12^2 \times 0.7854 \times 12 \times 12.7234}{41.2 \times 231} = 1.82\ \text{MIN.}$$

CLOSING OPERATION

NOMENCLATURE		WES MODEL		PROPOSED LOCK ALICEVILLE		FACTOR
TIME	T T_2	20.1 SEC'S 90 SEC'S	T_1	110		
ARC OF TRAVEL	K	71.567°	K_1	71.565°	$\dfrac{T_2}{T_A}$	$\dfrac{90}{110} = 0.82$

TIME T_1 = 110 SEC

$$\text{ADJUST } T_2 = T\sqrt{\frac{L_1}{L}} = 20.1\sqrt{20} = 20.1 \times 4.47 = 90$$

$$\text{ADJ. ANGULAR TRAVEL } T_A = T_1\left(\frac{K}{K_1}\right) = 110 \times 1 = 110$$

$$\text{FACTOR} = \frac{T_2}{T_A} = \frac{90}{110} = 0.82$$

$$P_1 = P\left(\frac{L_1}{L}\right)^4 \left(\frac{S_1}{S_2}\right)^{1.5} \left(\frac{T_2}{T_A}\right)^{1.0} \text{(BOTTOM EFFECT)}$$

$$= P\,(20)^4 (0.55)^{1.5} (0.82)^{1.0} \times \begin{pmatrix}\text{INCREASE DUE TO}\\\text{BOTTOM EFFECT}\end{pmatrix}$$

$$= P \times 160,000 \times 0.408 \times 0.82 \times 1.27$$

$$= P \times 68,000$$

CLOSING OPERATION

POSITION	(1) WES TORQUE ABOUT PINTLE LB-FT	(2) CORR. FACTOR	(3) TORQUE ABOUT PINTLE (ALICEVILLE) (3)=(1)×(2) LB-FT	(4) EFFECT. ARM ABOUT PINTLE FT	(5) FORCE IN STRUT (5)=(3)/(4)×1000 KIPS	(6) EFFECT. ARM ABOUT SECTOR FT	(7) TORQUE ABOUT SECTOR (0.95 EFF.) (7)=(5)×(6)/0.95 FT-KIPS	(8) SECTOR GEAR RADIUS FT	(9) FORCE ON PISTON (0.95 EFF.) (9)=(7)/(8)×0.95 KIPS	(10) CYL PRESS. (115.1 D") (10)=(9)/115.1×1000 +40 PSI loss PSI	(11) CYL PRESS. (115.1 D") PSI	(12) FORCE ON PISTON (0.95 EFF.) ×0.95 ×115.1/1000 KIPS	(13) TORQUE ABOUT SECTOR (0.95 EFF.) (13)=(12)×(8)×0.95 FT-KIPS	(14) FORCE IN STRUT (14)=(13)/(6) KIPS	(15) TORQUE ABOUT PINTLE (15)=(14)×(4) FT-KIPS
0	0	68×10³		19.71		6.16		5.0		0	900	96.7	459.	74.5	1470
0.1	40		2700×10³	19.68	137.	6.46	930		195	1760				71.0	1400
0.5	6.3		430×10³	19.64	22.	7.57	175		37.	370				60.6	1190
1.0	5.0		340×10³	19.70	17.3	8.13	159		38.	330				52.6	1040.
2	5.0		340×10³	19.91	17.1	10.48	189		40.	390				43.8	870
3	5.0		340×10³	20.00	17.0	11.47	205		45.	420				40.0	800
4	6.4		440×10³	19.67	22.	11.62	210		57.	540				39.5	780
5	8.0		540×10³	18.76	29.	10.80	330		69.	650				42.5	800
6	9.0		610×10³	16.99	56.	8.63	330		69.	650				53.2	900
7	20.0		1360×10³	13.32	102	3.20	340		72.	680				143.4	1910

REQUIRED LOADS | AVAILABLE TORQUE

SET AT 940 PSI — 100-PSI DROP

PRESS. ON HEAD 900 + 40 = 940 — SET AT 1200 PSI

50-PSI DROP

PRESSURE ON HEAD END DUE
TO RETURN LINE FRICTION =
50 × 93.5"/115.1 D" = 40 PSI ±
EFFECTIVE PRESSURE = 940 - 40 = 900 PSI
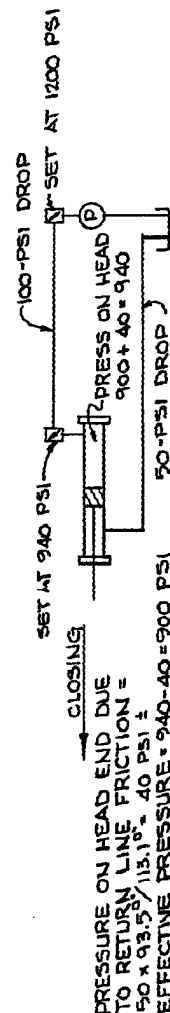
CLOSING →

* WHEN REQUIRED GATE TORQUE EXCEEDS AVAILABLE TORQUE, SOME HYDRAULIC OIL WILL BE BYPASSED AT RELIEF VALVE AND THE GATE WILL AUTOMATICALLY TRAVEL AT A SPEED THAT WILL REDUCE THE REQUIRED GATE TORQUE TO THE GATE TORQUE AVAILABLE FROM 900 PSI EFFECTIVE CYLINDER PRESSURE.
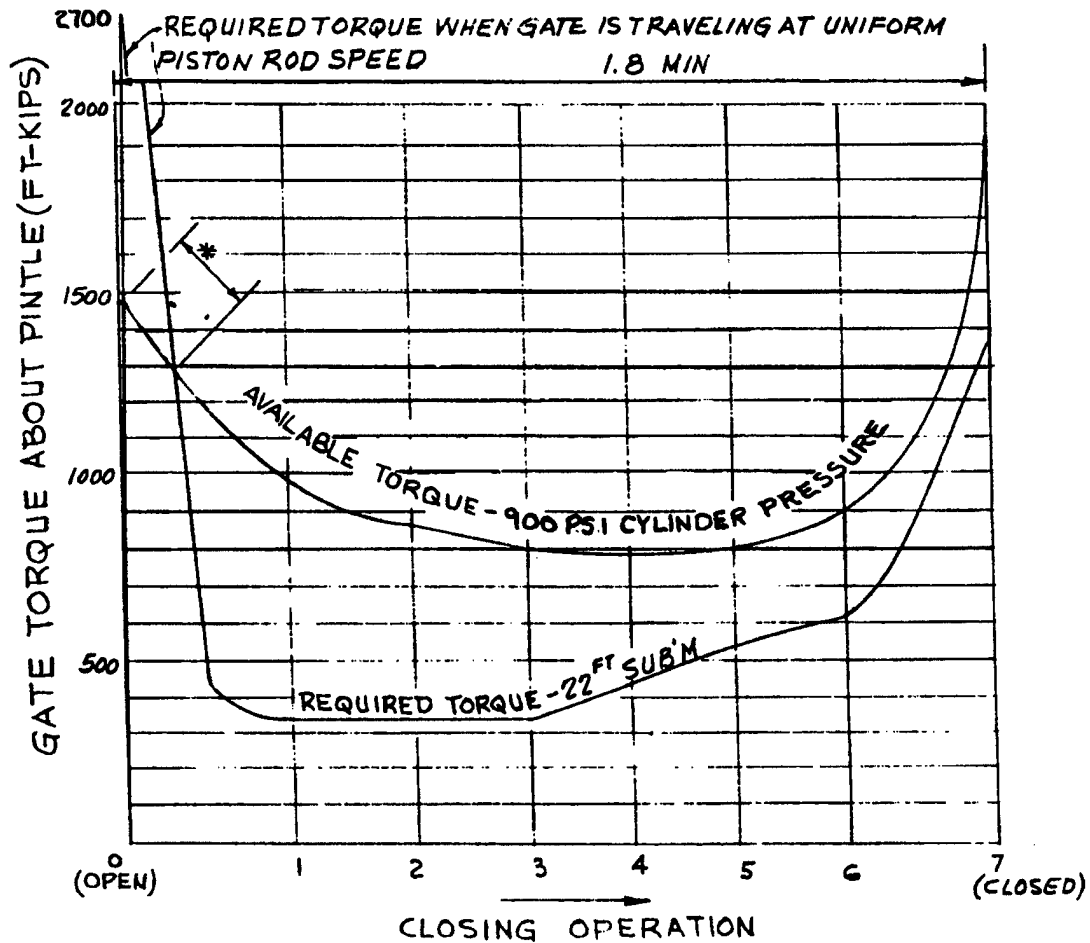
OHIO RIVER LINKAGE
GATE TORQUE ABOUT PINTLE
CLOSING TIME
1.8 MIN

PLATE B-79
(SHEET 10 OF 12)

TEMPORAL LOADING

FLOW

₵ LOCK

O*

O*

**

L₁

L₂

7*

GATE CLOSED

₵ PINTLE

** AREA OF TRAVEL WHERE NORMAL LOADS APPLY

* POSITION WHERE TEMPORAL LOADS APPLY

$$T_t = \frac{62.4}{4} (L_1^2 - L_2^2)(h_2^2 - h_1^2)$$

T_t = GATE TORQUE ABOUT PINTLE DUE TO TEMPORAL LOAD (FT-LB)

L_1 = GATE LENGTH PINTLE TO MITER (FT)

L_2 = GATE LENGTH PINTLE TO QUOIN (FT)

h_1 = GATE SUBMERGENCE (FT)

h_2 = GATE SUBMERGENCE PLUS TEMPORAL HEAD (FT)
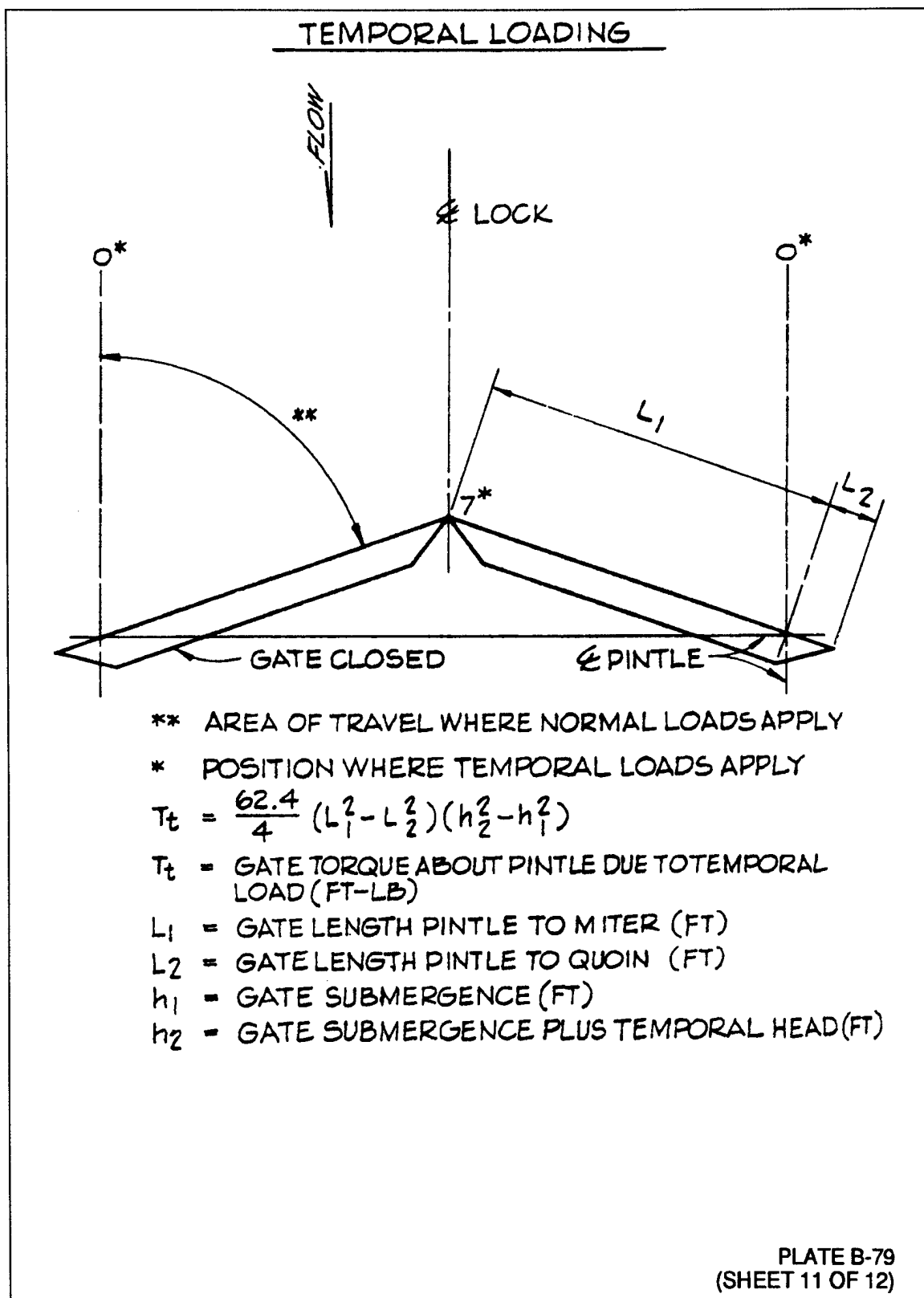
TEMPORAL FORCES EXAMPLE COMPUTATIONS

$$T_t = \frac{62.4}{4}\left(L_1^2 - L_2^2\right)\left(h_2^2 - h_1^2\right)$$

FOR ALICEVILLE LOCKS

L_1 = 718.34" = 59.86'
L_2 = 21.65" = 1.804'
h_1 = 22'
h_2 23.25'

$$T_t = \frac{62.4}{4}\left[(59.86)^2 - (1.804)^2\right]\left[(23.25)^2 - (22)^2\right]$$

$$T_t = \frac{62.4}{4}\left[3579.96\right]\left[56.56\right]$$

$$T_t = 3,159,000 \text{ FT-LB}$$

REFERENCE PLATE B-79, SHEET 9, POSITION 7

CALCULATE ⟶ THE FORCE IN THE STRUT FOR A
PINTLE TORQUE OF 3,159,000 FT-LB

STRUT FORCE = $\dfrac{3,159,000}{13.32}$ = 237,000 LB

TORQUE ABOUT SECTOR = $\dfrac{237,000}{0.95}$ = 798,000 FT-LB

FORCE ON PISTON = $\dfrac{798,000}{5.0 \times 0.95}$ = 168,000 LB

CYLINDER PRESSURE = $\dfrac{168,000}{113.1}$ + 40 PSI = 1525 PSI

A CYLINDER PRESSURE OF 1525 PSI IS REQUIRED
TO MAINTAIN THE GATE IN THE MITER POSITION
AGAINST A TEMPORAL HEAD OF 1.25 FT.

PLATE B-79
(SHEET 12 OF 12)

KINEMATICS
PANAMA CANAL LINKAGE
SCALE: 3/16"=1'-0"

PLATE B-80
(SHEET 1 OF 13)

EFFECTIVE ARMS

POS.	A ABT. GATE	B ABT. SECT.
O	20.0'	0.0'
½	19.67	4.72
1	19.13	6.63
2	19.63	9.17
3	20.00	10.38
4	19.92	11.00
5	19.25	10.25
6	17.67	8.00
6½	16.38	5.87
7	13.33	0.00

PLATE B-80
(SHEET 2 OF 13)

NL SPEED -MOTOR   1800
FL   "   "   1600

RPM OF SECTOR $= \dfrac{203.765}{1.65 \times 60} = 2.07 \,^{\circ}/sec \; \therefore \; \dfrac{2.07 \times 60}{360} = 0.345$

— AVERAGE OPERATING TIME

OVERALL RED. RATIO $= 1600/0.345 = 4640$ (MOTOR TO SECTOR)

OVERALL EFFICIENCY $= 0.98 \times 0.97 \times 0.92 \times 0.94 = 0.82$

PLATE B-80
(SHEET 3 OF 13)

PANAMA
LINKAGE

EL 145.0 (MAX)

EL 115.25   NORMAL OPERATION 82% TIME

— LOWER GATE

22'

— BOTTOM LOCK CHAMBER

EL 93.25

SILL

NORMAL OPERATION (ELECTRIC-MOTOR DRIVE)

ASSUME OPENING TIME = 99 SEC (SAME TOTAL TIME AS HYDR OPERATION)

$$HYD\ OPER = \left(\frac{1.5 + 1.8}{2}\right)60 = 99\ SEC$$

SUBMERGENCE = 22^{FT}

NOMENCLATURE		PANAMA CANAL		PROPOSED LOCK (ALICEVILLE)		FACTOR
LENGTH GATE	L	84.304	L_1	60.0	L_1/L	= 0.712
SUBMERGENCE	S S_2	82.5 58.7	S_1	22.0	$\frac{S_1}{S_2}$	= 0.375
TIME	T T_2	120 SEC 101.3 SEC	T_1	99.0	$\frac{T_2}{T_1}$	= 1.023 SEC
ARC OF TRAVEL	K	63.488°	K_1 T_A	71.565 111.7	$\frac{T_2}{T_A}$	= 0.907

FACTOR $\frac{L_1}{L} = \frac{60}{84.304} = 0.712$

SUBMERGENCE = 22

ADJ. SUBMERGENCE = $C = S_2\left(\frac{L_1}{L}\right) = 82.5 \times 0.712 = 58.7$

FACTOR $\frac{S_1}{S} = \frac{22}{58.7} = 0.375$

PLATE B-80
(SHEET 4 OF 13)

T_1 = TIME FOR PROPOSED LOCK = 99 SEC

T = TIME FOR PANAMA CANAL = 120 SEC

$T_2 = T\sqrt{\dfrac{L_1}{L}}$ = ADJ TIME = 101.3 MODEL

T_A = ANGULAR ADJ = $T_1\left(\dfrac{K_1}{K}\right)$ = 111.7

TIME T_1 = 99 SEC (PROPOSED GATE)

ADJ TIME = $T_2 = T\sqrt{\dfrac{L_1}{L}}$ = $120\sqrt{0.712}$ = 120 × 0.844 =

= 101.3 MODEL

ANGULAR TRAVEL $T_A = T_1\left(\dfrac{K_1}{K}\right)$ = $99\left(\dfrac{71.565}{63.436}\right)$ = 111.7 — ALICEVILLE

— PANAMA CANAL

FACTOR $\dfrac{T_2}{T_A}$ = $\dfrac{101.3}{111.7}$ = 0.907

EFFECT OF BOTTOM CLEARANCE - NO ADJUSTMENT
NECESSARY WHEN USING PANAMA TESTS

(NORMAL OPERATION 82% TIME)

$P_1 = P\left(\dfrac{L_1}{L}\right)^4\left(\dfrac{S_1}{S}\right)^{1.7}\left(\dfrac{T_2}{T_A}\right)^{1.3}$ P_0(FROM PANAMA TEST CURVES)

$= P(0.712)^4(0.375)^{1.7}(0.907)^{1.3}$

$= P(0.25)(0.188)(0.881)$ = $P_0(0.0414)$

(MAX SUB'MG - LESS THAN 18% TIME)

H = 145.0 - 93.25 = 51.75 - SAY 52'

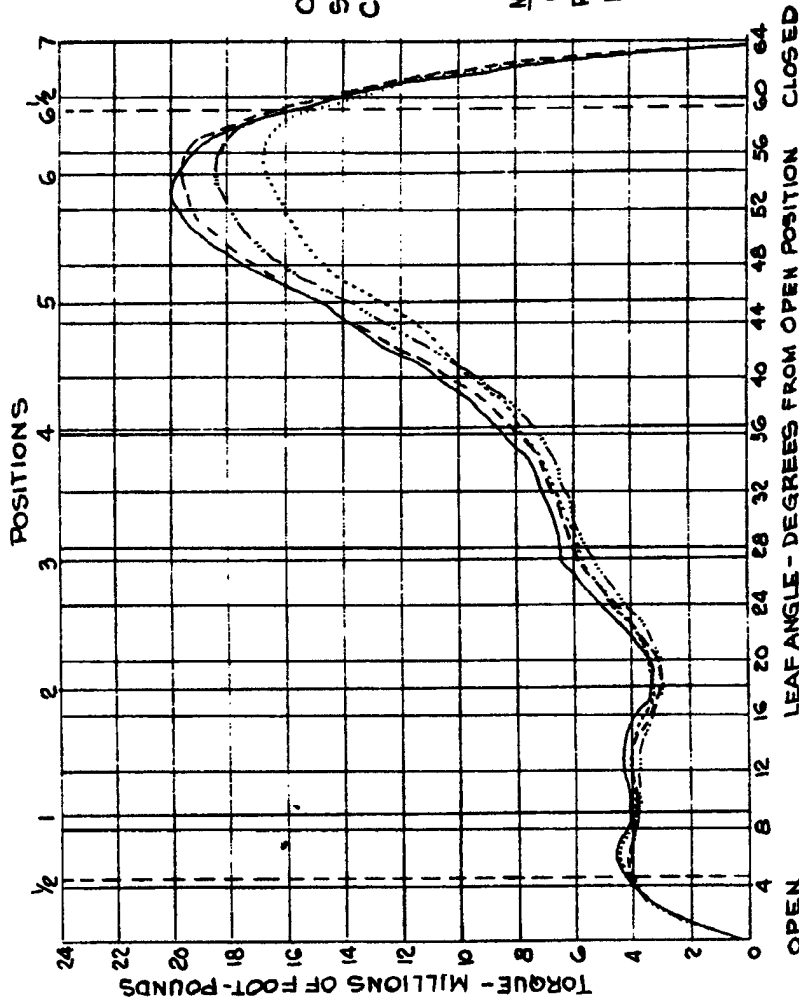ADJ FACTOR = $\dfrac{52}{58.7}$ = 0.8859

$P_1 = P(0.714)^4(0.8859)^{1.7}(0.907)^{1.3}$

$= P(0.25)(0.814)(0.881)$ = $P_0(0.1793)$

CORRECTION FACTOR FOR 52' SUB'MG.)

$\dfrac{P_{52}}{P_{22}}$ = $\dfrac{0.1793}{0.0414}$ = 4.33

BASE CONDITIONS

OPERATING TIME: 2 MIN
SUBMERGENCE: 82.5 FT
CHAMBER LENGTHS:
UPSTREAM: 1,105 FT
DOWN STREAM: 200 FT

NOTE:
CURVES SHOW VARIATION OF
RESULTS OBTAINED UNDER
IDENTICAL OPERATING
CONDITIONS.

THE PANAMA CANAL
SPECIAL ENGINEERING DIVISION
BALBOA HEIGHTS, CANAL ZONE
THE THIRD LOCKS PROJECT
HYDRAULIC MODEL Y
MITER GATE OPERATION
THIRD LOCKS TEST CURVES

PLATE B-80
(SHEET 6 OF 13)

BASE CONDITIONS

OPERATING TIME : 2 MIN
SUBMERGENCE : 82.5 F´
CHAMBER LENGTHS:
UPSTREAM : 1105 F´
DOWNSTREAM : 200 F´

NOTE:
CURVES SHOW VARIATION OF
RESULTS OBTAINED UNDER
IDENTICAL OPERATING
CONDITIONS.

FOR INFORMATION ONLY:
MOTOR WOULD BE SELECTED
ON THE OPENING CYCLE.

THE PANAMA CANAL
SPECIAL ENGINEERING DIVISION
BALBOA HEIGHTS, CANAL ZONE
THE THIRD LOCKS PROJECT
HYDRAULIC MODEL Y
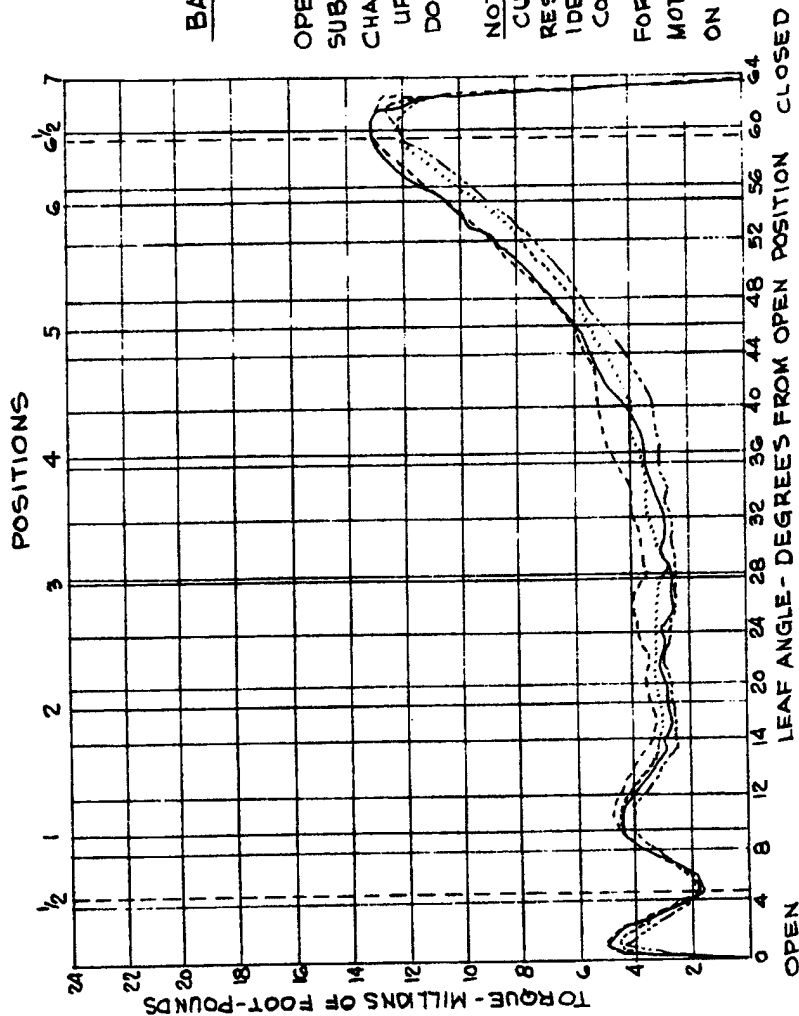MITER GATE OPERATION
THIRD LOCKS TEST CURVES

PLATE B-80
(SHEET 7 OF 13)

REQ'D POWER - OPENING OPERATION (22 FT SUB'M)

P.O.S.	TORQUE ABT PINTLE PANAMA C. FT-LB	CORR. FACTOR	TORQUE ABT PINTLE ALICEVILLE FT-KIPS	EFFECT. ARM ABT PINTLE FT	FORCE IN STRUT (0.98 EFF)	EFFECT. ARM ABT SECTOR FT	TORQUE ABT SECTOR (0.97 EFF)	REDUCT RATIO (0.845 EFF)	REQ'D MOTOR TORQUE FT-LBS	H.P. = $\frac{T \times RPM}{5250}$
0	0	0.0414	0	20.0	0	0	0	4640	0	0
0.5	4.0×10^6		165.6×10^3	19.67	8.59 K	4.92	43.6 K		10.9	3.32
1	3.8×10^6		157.3×10^3	19.13	8.39 K	6.63	57.4 K		14.3	4.4
2	3.0×10^6		124.2×10^3	19.63	6.46 K	9.17	61.0 K		15.2	4.6
3	5.9×10^6		244.3×10^3	20.00	12.46 K	10.38	133.4 K		33.2	10.1
4	7.9×10^6		327.0×10^3	19.92	16.75 K	11.00	190.0 K		47.3	14.4
5	14.0×10^6		579.6×10^3	19.25	30.70 K	10.25	324.7 K		80.9	24.7
6	18.4×10^6		761.8×10^3	17.67	43.99 K	8.00	362.8 K		90.4	27.5
6½	15.4×10^6		637.6×10^3	16.38	39.72 K	5.87	240.4 K		59.9	18.3
7	0		0	13.33	0	0	0		0	0

PLATE B-80
(SHEET 8 OF 13)

FORCES AT MAX SUB'M. (52 FT)

REQUIRED POWER - OPENING OPERATION

P.O.S.	TORQUE FROM P.C.CURVES	CORR. FACTOR $= \dfrac{0.1793}{0.0414}$	FORCE IN STRUT 22-FT SUB'M.	FORCE IN STRUT 52-FT SUB'M.	TORQUE ABT PINTLE 22-FT SUB'M.	TORQUE ABT PINTLE 52-FT SUB'M.
0	0	4.33	0	0	0	0
0.5	4.0×10^6		8.59^K	37.2	165.6×10^3	717.1×10^3
1	3.8×10^6		8.39^K	36.3	157.3×10^3	681.1×10^3
2	3.0×10^6		6.46^K	28.0	124.2×10^3	537.8×10^3
3	5.9×10^6		12.46^K	53.9	244.3×10^3	1057.8×10^3
4	7.9×10^6		16.75^K	72.5	327.0×10^3	1415.9×10^3
5	14.0×10^6		30.70^K	132.9	579.6×10^3	2509.6×10^3
6	18.4×10^6		43.99^K	190.5	761.8×10^3	3298.6×10^3
$6\frac{1}{2}$	15.4×10^6		39.72^K	172.0	637.6×10^3	2760.8×10^3
7	0		0	0	0	0

MOTOR SELECTION

22' SUB.   MOTOR MUST PROVIDE REQ'D TORQUE AT ALL POSITIONS AND AT NORMAL SPEED.

52' SUB.   MOTOR MUST PROVIDE PEAK TORQUE W/OUT EXCEEDING 150% OF F.L.T. GATE WILL BE SLOWED DUE TO MOTOR SPEED LOSS AT OVERLOAD. THEREFORE REQ'D TORQUE AS SHOWN IN PLATE B-80, SHEET 11, WOULD REQUIRE CORRECTION.

PEAK OCCURS AT POS 6.
TORQUE ABOUT PINTLE = $3,298.6^{FT-LB}$ FOR NORMAL SPEED.

AT 150 % O.L.
MOTOR SPEED = (1,800)(0.77) = 1,386 RPM

1. GATE SPEED AT 1,386 MOTOR RPM

$$T_1 = (99)\left(\frac{1386}{1,600}\right) = 114 \text{ SEC}$$

2. ADJ PINTLE TORQUE FOR CHANGED TIME

$T_1 = 114$

$T_2 = 101.3$

$$T_A = 114\left(\frac{71.565}{63.436}\right) = 128.6$$

FACTOR $T_2/T_A = 101.3 / 128.6 = 0.788$

3. CALCULATE PINTLE TORQUE AT POS 6

$$P_1 = P_o(0.25)(0.814)(0.788)^{1.3}$$
$$= P_o(0.204 * 0.73) = P_o(0.149)$$
$$P_1 = 18.4 \times 10^6 * 0.149 = 2,742 \text{ FT-KIPS}$$

4. MOTOR TORQUE AT 150% OL.

$$\text{MOTOR TORQUE} = \frac{2742 \overset{\text{FT-KIPS}}{\times} 8.00}{17.67 * 0.98 * 0.97 * 4640 * 0.865} = 322. \text{ FT-LB}$$

$$\text{NORMAL F.L. TORQUE} = \frac{322}{1.5} = 214.7 \text{ FT-LB}$$

$$\text{MOTOR HP} = \frac{214.7 * 1600}{5250} = 65.4 \text{ HP}$$

75 HP REQUIRED.

AVAILABLE POWER-OPENING OPERATION

P O S	F.L.* MOTOR TORQUE	RED. RATIO TORQUE (0.865 EFF.)	TORQUE ABT SECTOR	EFFECT. ARM ABT SECTOR (0.97)	FORCE IN STRUT	EFFECT. ARM ABT PINTLE	EFFECT. TORQUE ABT PINTLE (0.98 EFF.)
0	246 FT.LB	4640	987.3	0	0	20.00	0
0.5				4.92	194.6	19.67	3752 FT/K
1				6.63	144.4	19.13	2708
2				9.17	104.4	19.63	2009
3				10.38	92.3	20.00	1808
4				11.00	87.1	19.92	1700
5				10.25	93.4	19.25	1762
6				8.00	119.7	17.67	2073
6½				5.87	163.1	16.38	2619
7				0	0	13.33	0

* 75 HP AT 1,600 RPM F.L. SPEED

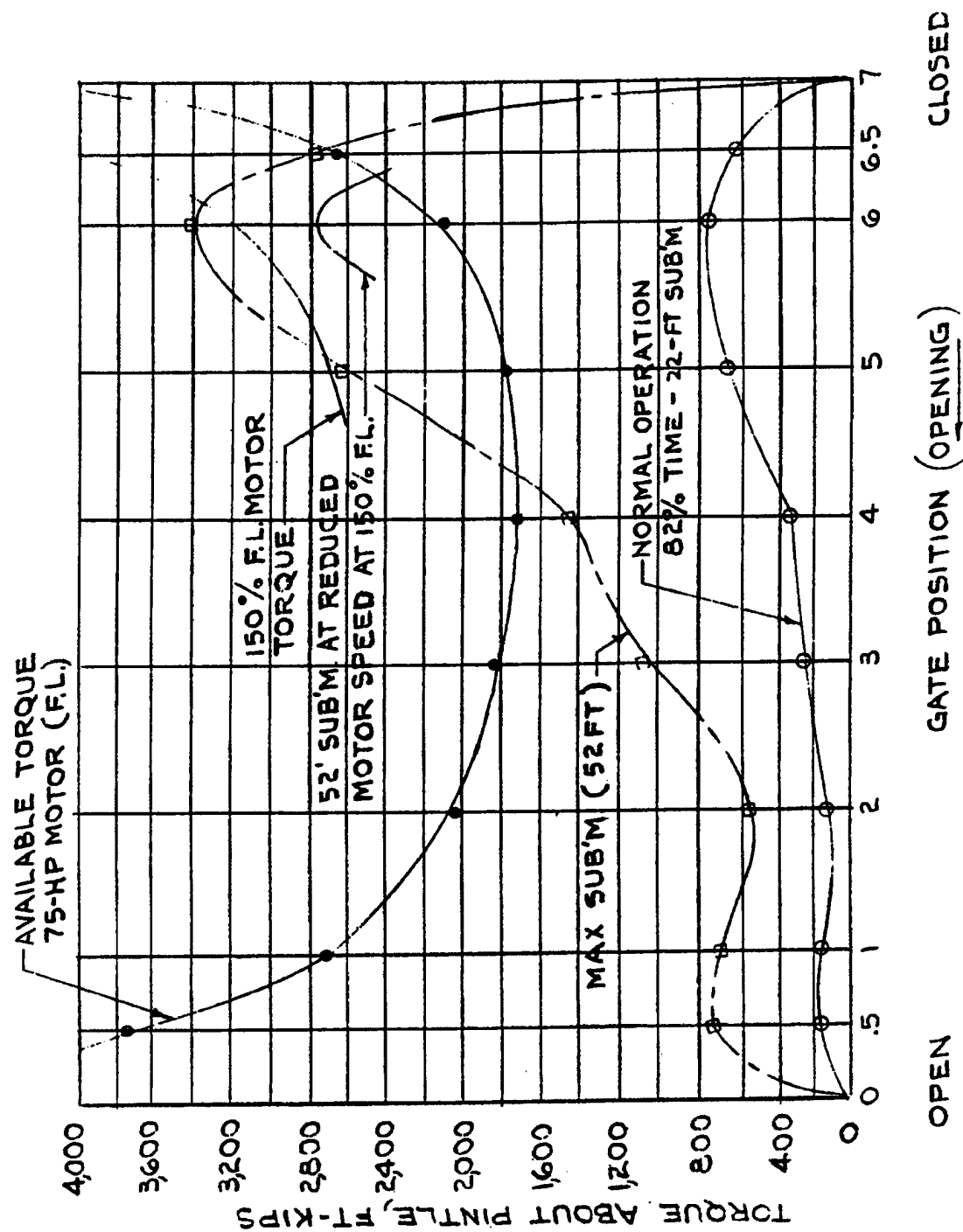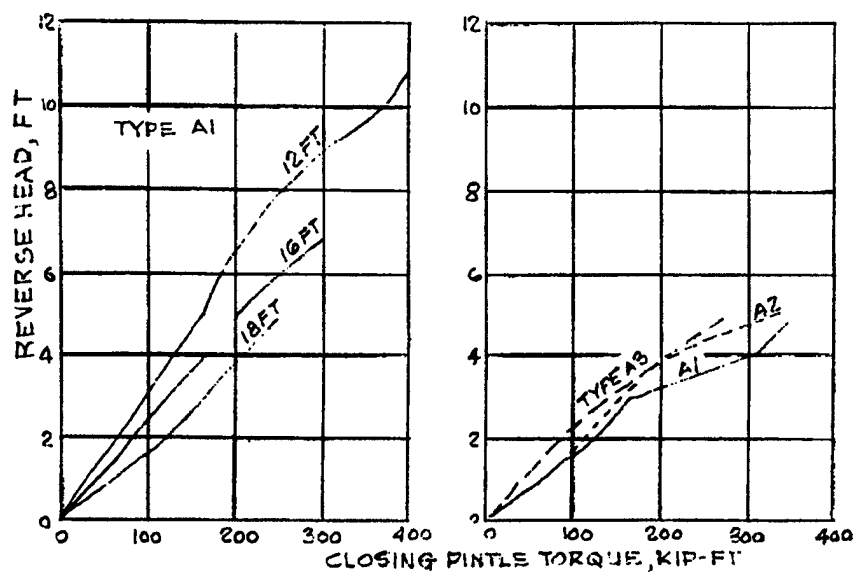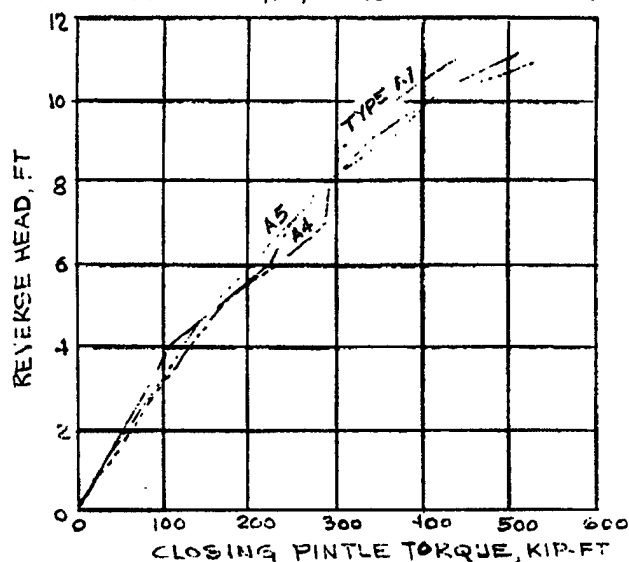$$T = \frac{HP \times 5250}{RPM} = 246 \text{ FT-LB}$$

PLATE B-80
(SHEET 12 OF 13)

a. GATE OPEN 5 FT
LOWER POOL DEPTHS 12, 16, AND 18 FT

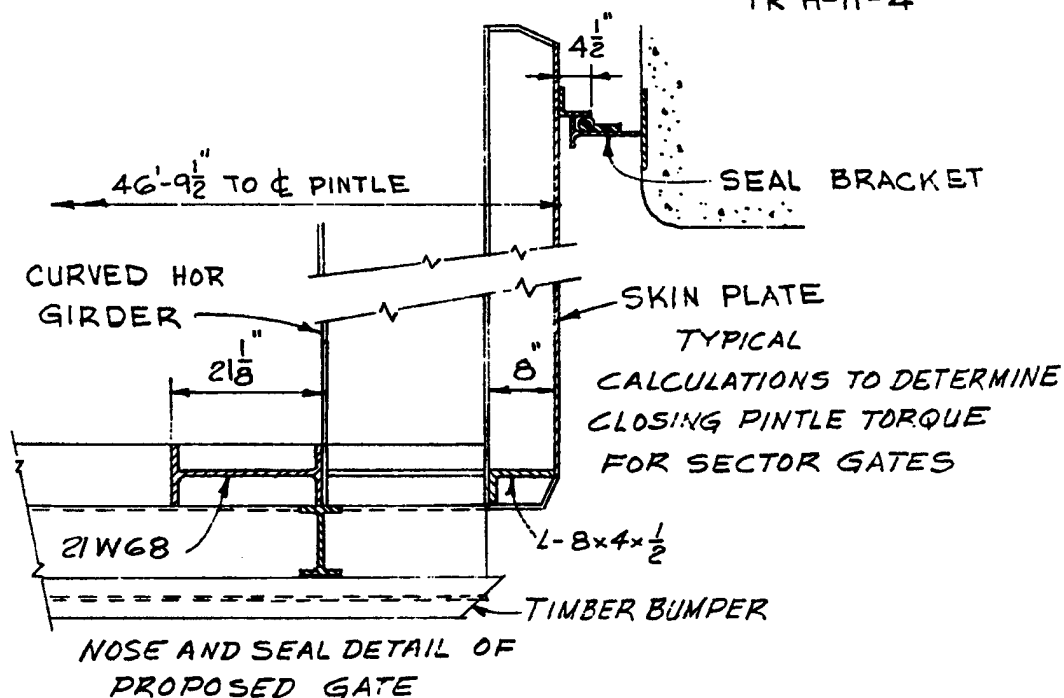b. GATE OPEN 5 FT
LOWER POOL DEPTH 18 FT

c. GATE OPEN 7 FT   LOWER POOL DEPTH 12 FT

FROM WES OPERATING
FORCES ON SECTOR GATES
WES REPORT H-70-2,
UNDER REVERSE HEADS.
APPENDIX A, PLATE A-4

EFFECTS OF
REVERSE HEAD ON
CLOSING PINTLE TORQUE
PLATE B-81

SECTOR GATE DESIGN
PINTLE TORQUE FOR REVERSE HEAD

WES TECHNICAL REPORT H-70-2 AND PROTOTYPE STUDY
TR H-71-4

$4\frac{1}{2}"$

$46'-9\frac{1}{2}"$ TO ₵ PINTLE

SEAL BRACKET

CURVED HOR
GIRDER

SKIN PLATE
TYPICAL
CALCULATIONS TO DETERMINE
CLOSING PINTLE TORQUE
FOR SECTOR GATES

$21\frac{1}{8}"$

$8"$

21 W 68

∠-8×4×$\frac{1}{2}$

TIMBER BUMPER

NOSE AND SEAL DETAIL OF
PROPOSED GATE

PROJECTED WIDTH OF MITER BEAM, SKIN PLATE RIB AND SEAL
PLATE BRACKET = $21\frac{1}{8}" + 8" + 4\frac{1}{2}" = 33.625"$

RADIUS OF GATE = $46'-9\frac{1}{2}" = 46.792'$

DESIGN CONDITIONS:
      $5'$ REVERSE HEAD
      $16'$ TAILWATER

(1) TO OBTAIN PEAK PINTLE TORQUE DUE TO WATER LOAD
   ONLY SEE CURVES, FIG. a, PLATE B-81, FOR $5'$ REVERSE
   HEAD AND $16'$ TAILWATER. = 200 FT-KIPS

   FIG. a IS DEVELOPED FOR A GATE WITH RADIUS OF 42 FT
   AND TOTAL PROJECTED WIDTH OF MITER BEAM, SKIN PLATE RIB,
   AND SEAL BRACKET OF $30.375"$

   $= 17\frac{7}{8}" + 8" + 4\frac{1}{2}" = 30.375"$ (SEE WES TECHNICAL REPORT, H-70-2 APP. A, PLATE AI)

**SECTOR GATES,
DETERMINATION OF
TOTAL PINTLE TORQUE**

CORRECT MODEL TORQUE FOR RADIUS AND PROJECTED AREA

$$T = 200^{FT/K} \left(\frac{33.625"}{30.375"}\right) \left(\frac{46.792'}{42.0}\right) = 247^{FT/K}$$
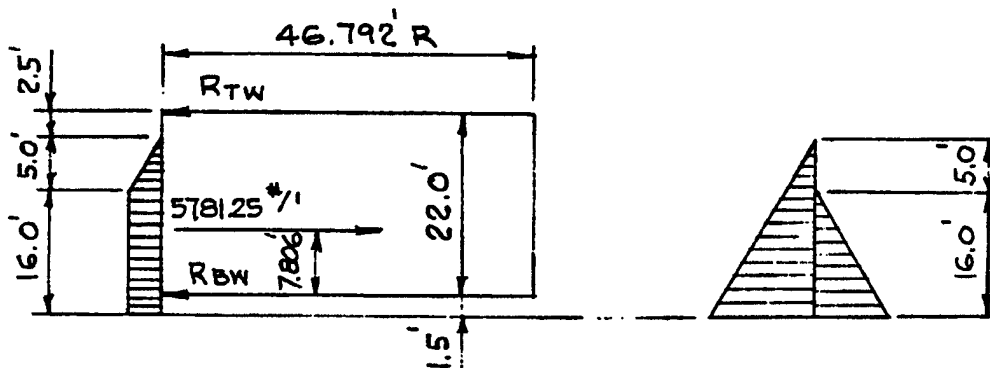
(2) COMPUTE TORQUE DUE TO DEAD LOAD AND STATIC WATER
   LOAD FRICTION:

<u>DEAD LOAD</u>
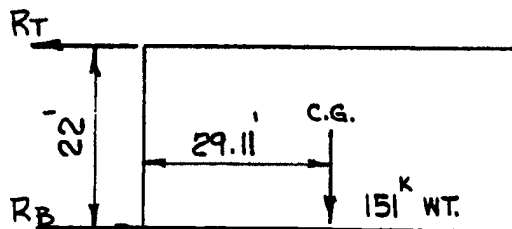
ASSUME:

WEIGHT OF GATE $= 151.0^K$

HINGE PIN DIAM $= 12"$

PINTLE PIN DIAM $= 18"$

$$R_T = R_B = \frac{151^K \times 29.11'}{22'} = 200^K$$

<u>WATER LOAD</u>

$62.5 \times 5'-0" = 312.5^{\#}/\square'$

$312.5 \times \dfrac{5'-0"}{2} = 781.25^{\#}/'$

$312.5 \times 16' = \underline{5000.00}$

$\qquad\qquad\qquad 5,781.25^{\#}/'$

$781.25 \times 16.167' = 12,630.47^{'\#}$

$5000 \times 6.50' = \underline{32,500.00}^{'\#}$

$\qquad\qquad\qquad 45,130.47^{'\#}$

$C.G = \dfrac{45,130.47}{5,781.25} = 7.806'$

$$R_{TW} = \frac{5781.25 \times 7.806}{22} \times 53.716' = 110.2^K$$

$$R_{BW} = (5781.25 \times 53.716') - 110.2^K = 200.3^K$$

(53.716' IS THE CHORD LENGTH BEHIND THE SKIN PLATE, NOT
   THE RADIUS OF THE GATE)

PLATE B-82
(SHEET 2 OF 3)

HINGE FRICTION TORQUE

ASSUME: (a) WEIGHT OF GATE ACTING AT ONE-HALF OF PIN RADIUS $= 9.0"/2 = 4.5"$

(b) COEFFICIENT OF FRICTION FOR PINS $= 0.25$

$$T_{HF} = \left(200^K \times 0.25 \times \frac{6"}{12}\right) 4.5^* + \left(110.2^K \times 0.25 \times \frac{6"}{12}\right)$$

$$= 112.5 \text{ FT-KIPS} + 13.8 \text{ FT-KIPS} = 126.3 \text{ FT-KIPS}$$

* PROTOTYPE FRICTION WAS FOUND TO BE 4.5 TIMES THE CALCULATED FRICTION (SEE WES TECHNICAL REPORT H-71-4, PAR. 14, WES 1971)

$$T_{PF} = \left(151^K \times 0.25 \times \frac{4.5"}{12}\right) 4.5^* + \left(200^K \times 0.25 \times \frac{9}{12}\right) 4.5^* -$$

$$\left(200.3^K \times 0.25 \times \frac{9"}{12}\right) = 63.7 \text{ FT-KIPS} + 168.75 \text{ FT-KIPS} - 37.6 \text{ FT-KIPS}$$

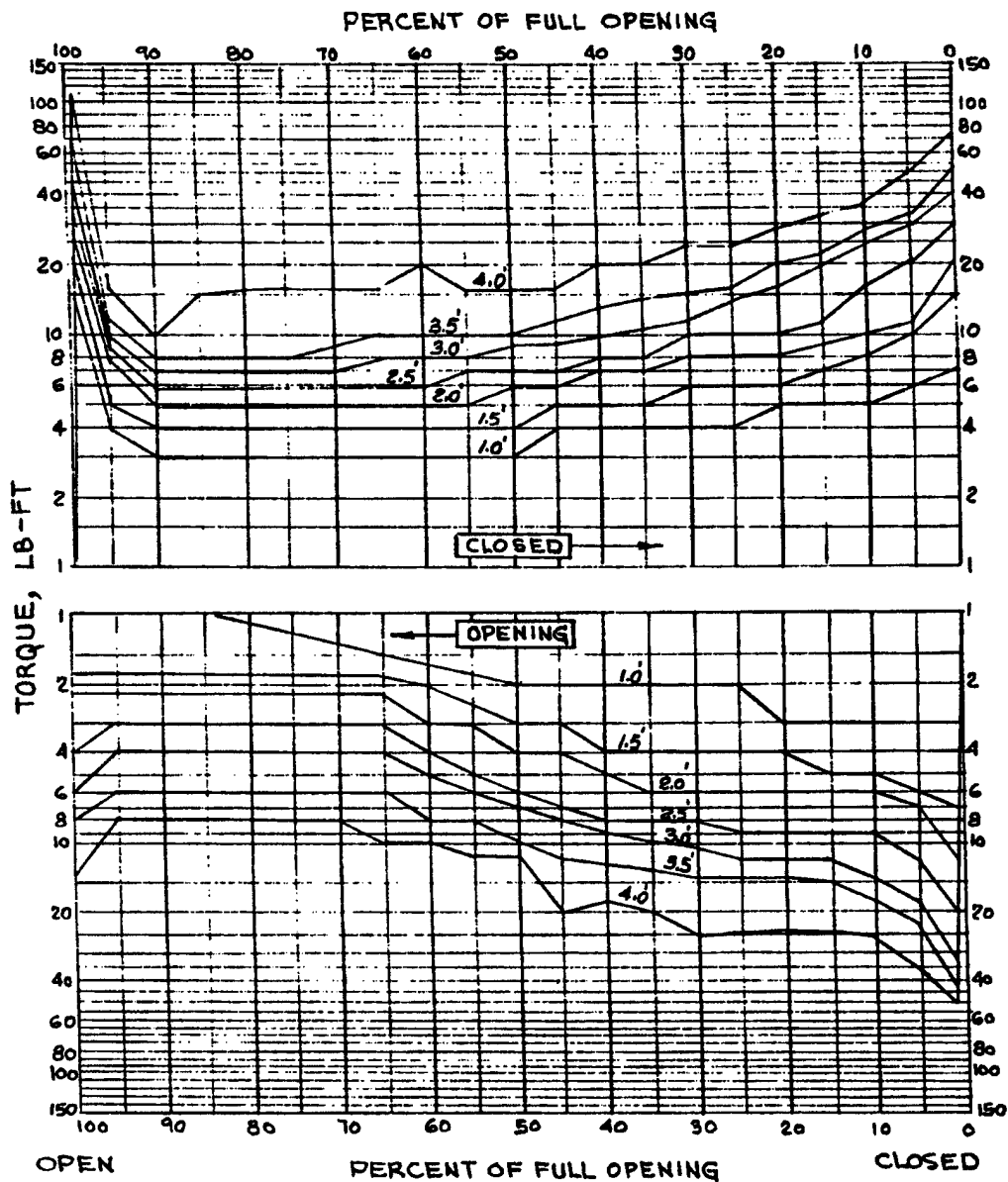$$= 194.8 \text{ FT-KIPS}$$

TOTAL FRICTIONAL TORQUE

$$= 126.3 \text{ FT-KIPS} + 194.8 \text{ FT-KIPS} = 321.1 \text{ FT-KIPS}$$

TOTAL TORQUE FOR DESIGN OF MACHINERY

$$= 247.0 \text{ FT-KIPS} + 321.1 \text{ FT-KIPS} = 568.1 \text{ FT-KIPS}$$

NOTE:

THERE WILL BE NO MOMENT DUE TO SEAL FRICTION AS REVERSE HEAD ELIMINATES MITER SEAL FRICTION.

PLATE B-82
(SHEET 3 OF 3)

PERCENT OF FULL OPENING

TORQUE, LB-FT

CLOSED

OPENING

OPEN

PERCENT OF FULL OPENING

CLOSED

SUBMERGENCE - AS SHOWN IN FEET
CHAMBER LENGTH
   UPSTREAM - 25 FT
     DOWNSTREAM - 25 FT
BOTTOM CLEARANCE 0.25 FT

MITER GATES
OHIO RIVER LINKAGE
EFFECT OF SUBMERGENCE
ON INSTANTANEOUS TORQUE
OPERATING TIME, 20.1 SEC
PLATE B-83

PERCENT OF FULL OPENING

TORQUE, LB-FT

CLOSING →

← OPENING

OPEN   PECENT OF FULL OPENING   CLOSED
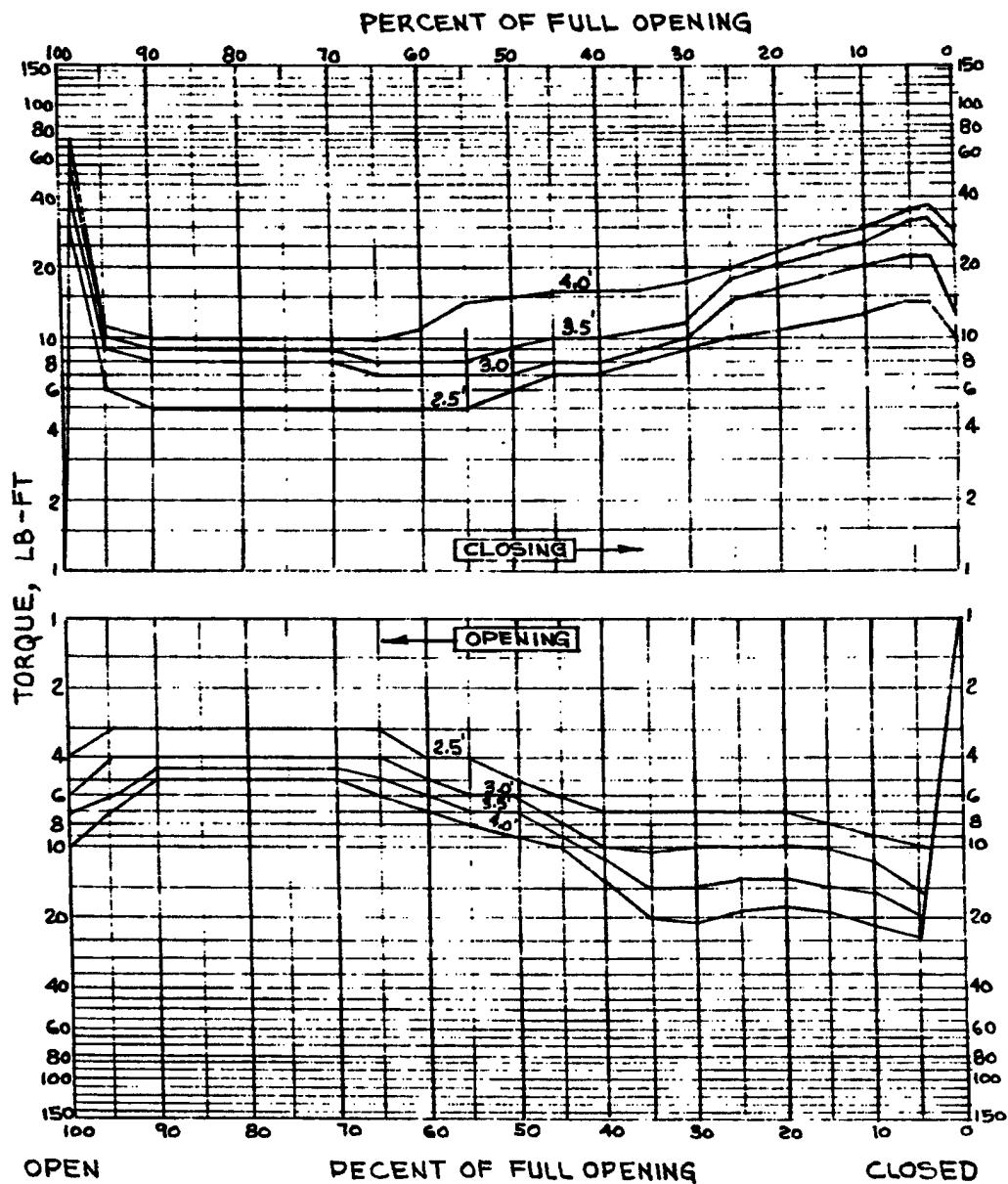
SUBMERGENCE - AS SHOWN IN FEET
BOTTOM CLEARANCE 0.25 FT

**MITER GATES
MODIFIED OHIO RIVER LINKAGE**
EFFECT OF SUBMERGENCE
ON INSTANTANEOUS TORQUE
OPERATING TIME, 20.1 SEC
CHAMBER LENGTHS, 30 FT

BASE CONDITIONS

OPERATING TIME : 2 MIN
SUBMERGENCE : 82.5 FT
CHAMBER LENGTHS:
 UPSTREAM : 1,105 FT
 DOWN STREAM : 200 FT

NOTE:
 CURVES SHOW VARIATION
 OF RESULTS OBTAINED UNDER
 IDENTICAL OPERATING
 CONDITIONS.

MITER GATES
THE PANAMA CANAL
SPECIAL ENGINEERING DIVISION
BALBOA HEIGHTS, CANAL ZONE
THE THIRD LOCKS PROJECT
HYDRAULIC MODEL Y
MITER GATE OPERATION
THIRD LOCKS TEST CURVES

LEAF ANGLE, DEG FROM OPEN POSITION

CLOSING OPERATION

TORQUE, MILLIONS OF FOOT-POUNDS

PLATE B-85

BASE CONDITIONS

OPERATING TIME: 2 MIN
SUBMERGENCE: 82.5 FT
CHAMBER LENGTHS:
UPSTREAM: 1,105 FT
DOWNSTREAM: 200 FT

NOTE:
CURVES SHOW VARIATION OF
RESULTS OBTAINED UNDER
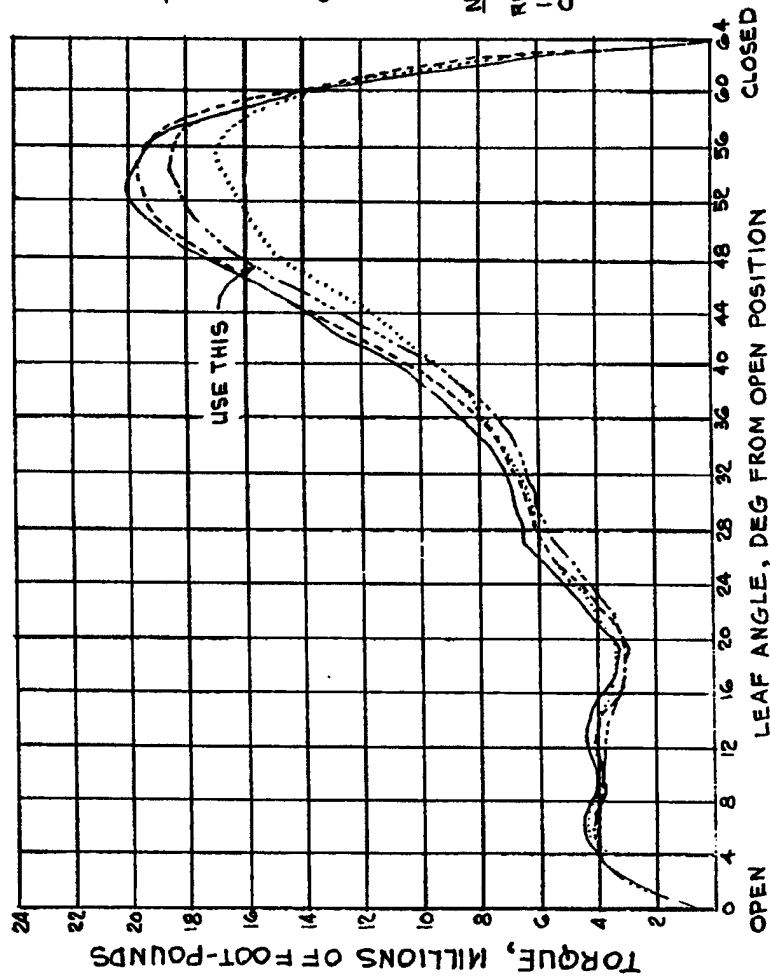IDENTICAL OPERATING
CONDITIONS.

MITER GATES
THE PANAMA CANAL
SPECIAL ENGINEERING DIVISION
BALBOA HEIGHTS, CANAL ZONE
THE THIRD LOCKS PROJECT
HYDRAULIC MODEL Y
MITER GATE OPERATION
THIRD LOCKS TEST CURVES

PLATE B-86

$\mathcal{C}$ CYLINDER & GIMBAL BRACKET

8'−3"

5'−3"

0

EFF ARM ABOUT PINTLE
TYP POS 0 & 10

1.

2.

3.

4.

$\mathcal{C}$ PINTLE

71°−34' TRAVEL ANGLE

10.7682' STROKE

5.

6.

7.

8.

9.

9.5

10

26'−23'

GATE LENGTH = 48 FT

18'−26'

$\mathcal{C}$ PINTLE

GATE CONNECTION

FLOW

KINEMATICS
DIRECT CONNECTED CYLINDER
SCALE: 1"=3'-0"

PLATE B-87
(SHEET 1 OF 10)

DESIGN CRITERIA (OPENING OPERATION) 80% TIME

OPENING TIME: ASSUME 90 SEC ($1\frac{1}{2}$ MIN) SEE PLATE B-87, SHEET 3
SUBMERGENCE: ASSUME 34 FT. (80% TIME OR LESS)
STROKE OF PISTON: 10.768 FT.

NOMENCLATURE		MODEL (CLAIBORNE L.)		PROPOSED LOCK		FACTOR
LENGTH GATE	L	48.0	L_1	48.0	$\frac{L_1}{L}$	1.0
SUBMERGENCE	S S_2	23.6' 23.6	S_1	34.0	$\frac{S_1}{S_2}$	1.441
TIME	T T_2	109 109	T_1	90	$\frac{T_2}{T_1}$	1.211
ARC OF TRAVEL	K	71.567°	K_1	71.567°	$\frac{K}{K_1}$	1.00

SINCE LENGTH OF GATE, ARC OF TRAVEL, AND CLEARANCE UNDER
GATE ARE THE SAME ON MODEL AND PROPOSED LOCK, NO
ADJUSTMENTS ARE REQUIRED, FOR THESE FACTORS.
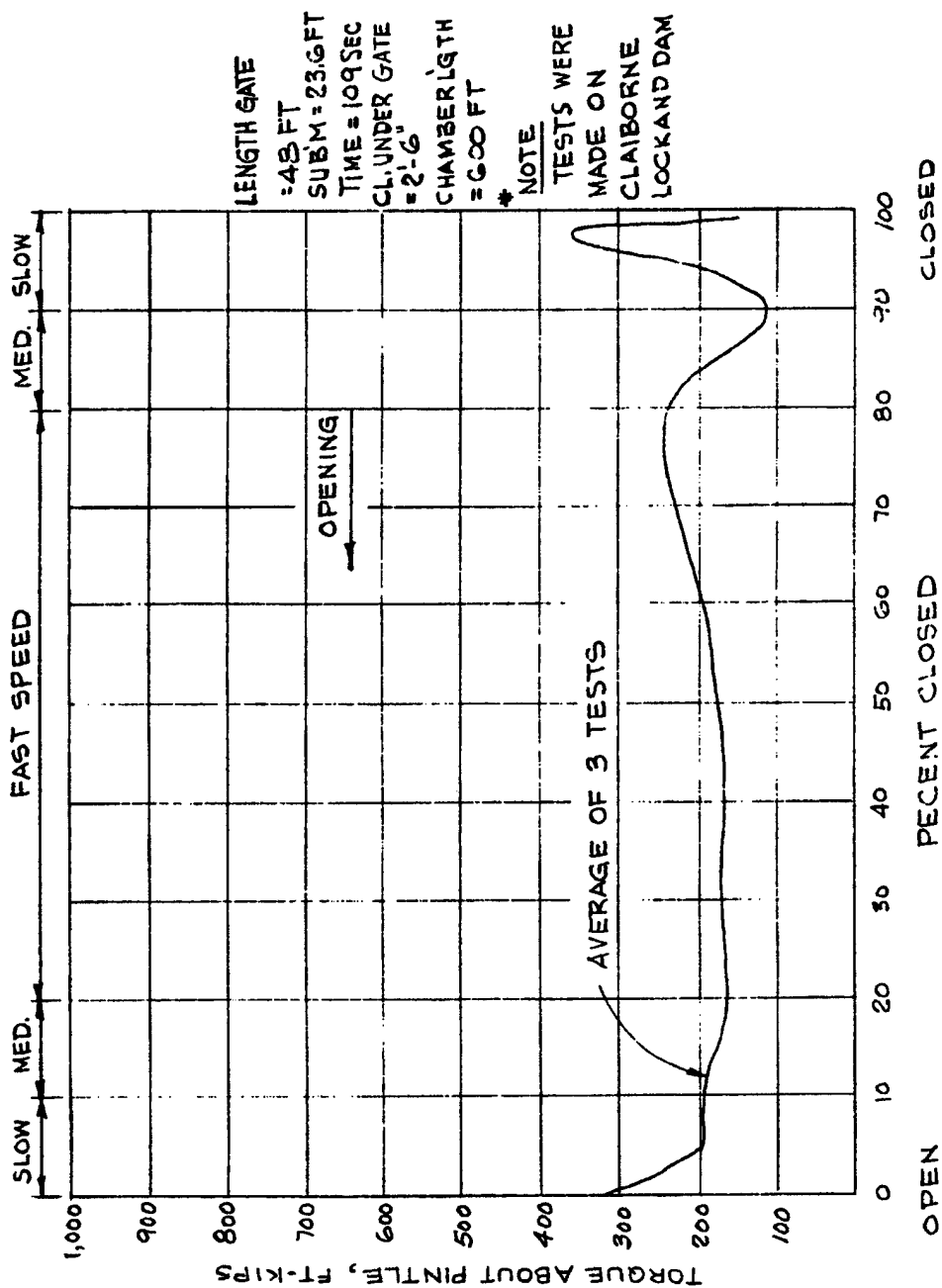
PLATE B-87
(SHEET 2 OF 10)

TESTS 1A, 2A, AND 3A
VARIABLE SPEED OPERATION
TIME, 109 SEC

OPENING GATE

$$P_1 = P\left(\frac{L_1}{L}\right)^4 \left(\frac{S_1}{S_2}\right)^{1.7} \left(\frac{T_2}{T_1}\right)^{1.3}$$

$$= P(1.0)^4 (1.441)^{1.7} (1.211)^{1.3} = P \times 1.86 \times 1.283$$

$$P_1 = 2.39 \times P$$

CLOSING GATE

NOMENCLATURE		MODEL (CLAIBORNE L.)		PROPOSED LOCK		FACTOR
LENGTH GATE	L	48.0 FT	L_1	48.0 FT	$\frac{L_1}{L}$	1.0
SUBMERGENCE	S S_2	23.6 23.6	S_1	34.0	$\frac{S_1}{S}$	1.441
TIME	T T_2	140 SEC 140 SEC	T_1	113	$\frac{T_2}{T_1}$	1.24
ARC OF TRAVEL	K	71.567	K_1	71.565	$\frac{K}{K_1}$	1.0

$$P_1 = P\left(\frac{L_1}{L}\right)^4 \left(\frac{S_1}{S}\right)^{1.5} \left(\frac{T_2}{T_1}\right)^{1.1}$$

$$= P(1.0)^4 (1.441)^{1.5} (1.24)^{1.1} = P \times 1.0 \times 1.73 \times 1.267$$
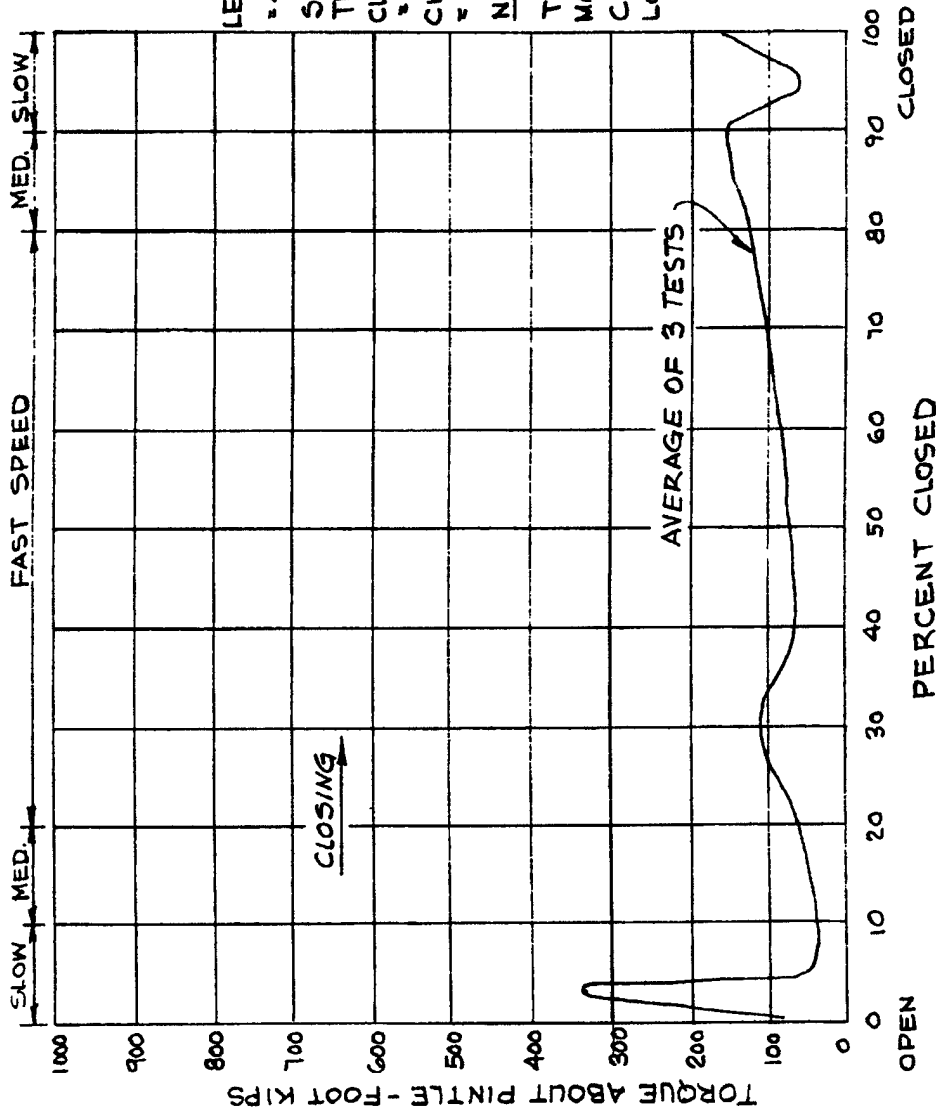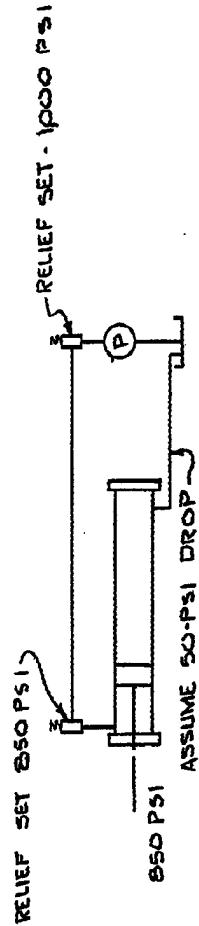
$$P_1 = 2.19 P$$

PLATE B-87
(SHEET 4 OF 10)

TESTS 1A, 2A, AND 3A
VARIABLE SPEED OPERATION
TIME, 140 SEC

OPENING GATE

		REQUIRED TORQUE									AVAILABLE TORQUE		
①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	⑫	⑬	
POS	MODEL TORQUE (CLAIBORNE) (FT-KIPS)	ADJ FACTOR	TORQUE ABT PINTLE (PROPOSED) FT-KIPS ②×③	EFFECT ARM ABOUT PINTLE (FT)	FORCE ON PISTON ROD (ROD END) KIPS ④÷⑤÷0.97*	NET AREA HEAD END (SQ IN)	RETARDING FORCE DUE TO 50 PSI FRIC KIPS ⑦×150 PSI	REQ'D FORCE ROD END KIPS ⑥+⑧	REQ'D CYL PRESS ROD END PSI ⑨÷1000÷**	AVAIL CYL PRESS PSI	AVAIL PISTON FORCE KIPS ⑪×150.83× PSI÷1000-⑧	AVAIL TORQUE ABOUT PINTLE FT-KIPS ⑫×⑤	
CLOSED 10	0	2.39	0	7.4792	0	201.1	10.1	0	0	850	114.3	854.6	
9½	360		860.4	7.6790	112.0			122.1	810			877.4	
9	115		274.8	7.8958	35.9			45.9	305			902.2	
8	230		549.7	8.2917	68.3			78.4	520			947.4	
7	225		537.8	8.6250	64.3			74.3	443			985.5	
6	185		442.1	8.8458	51.2			61.2	407			1016.4	
5	175		418.3	9.1042	47.4			57.3	381			1040.2	
4	170		406.3	9.2083	45.5			55.6	369			1052.1	
3	175		418.3	9.1875	46.9			57.0	378			1049.7	
2	160		382.4	8.4792	43.9			54.0	358			1025.9	
1	190		454.1	8.4688	55.3			65.4	433			967.6	
0 OPEN	315		752.8	7.4792	105.8			113.9	753			854.6	

* 0.97 - EFFIC MACHINE
** AREA ROD END = 150.83 □"

RELIEF SET 850 PSI

850 PSI

ASSUME 50-PSI DROP

RELIEF SET - 1000 PSI

PROPOSED LOCK
SUBMERGENCE = 34 FT
TIME = 90 SEC

GATE TORQUE ABOUT PINTLE, FT-KIPS

AVAILABLE ~ 850 PSI

REQUIRED

PERCENT CLOSED

OPENING OPERATION

CLOSING GATE

			REQUIRED TORQUE							AVAILABLE TORQUE		
①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	⑫	⑬
POS	MODEL TORQUE (CLAIBORNE) (FT. KIPS)	ADJ FACTOR	TORQUE ABT. PINTLE (PROPOSED L.) FT.-KIPS ②x③	EFFECT. ARM ABOUT PINTLE (FT)	FORCE ON PISTON ROD (HEAD END) KIPS ④÷⑤÷0.97**	NET AREA ROD END (SQ IN)	RETARDING FORCE DUE TO 100-PSI FRICT. KIPS ⑦x100 PSI	REQ'D FORCE HEAD END KIPS ⑥+⑧	REQ'D CYL PRESS. HEAD END PSI ⑨÷200**	AVAIL. CYL. PRESS. PSI	AVAIL. PISTON FORCE KIPS ⑪x200-⑧÷1000	AVAIL. TORQUE ABOUT PINTLE FT.-KIPS ⑫x⑤
OPEN 0	0	2.19	0	7.4792	0	150.83	0	0	0	550	91.7	686
½	330		722.7	8.0790	92.2		15.1	107.3	534			741
1	35		76.7	8.4688	9.3			24.4	121			777
2	65		142.5	8.9792	16.4			31.5	157			823
3	110		240.9	9.1875	27.0			42.1	209			842
4	70		153.3	9.2083	17.2			32.3	161			844
5	75		164.3	9.1042	18.6			33.7	168			835
6	85		186.2	8.8958	21.6			36.7	182			816
7	100		219.0	8.6250	26.1			41.3	206			791
8	125		273.8	8.2917	34.0			49.1	245			760
9	160		350.4	7.8958	45.8			60.9	304			724
10 CLOSED	165		361.4	7.4792	49.8			64.9	324			686

* 0.97 - EFFIC MACHINE
** AREA HEAD END - 2001

RELIEF SET - 550 PSI

RELIEF SET - 1000 PSI

ASSUME 100-PSI DROP

PROPOSED LOCK
SUBMERGENCE = 34 FT
TIME = 113 SEC

1.88 MINUTES

AVAILABLE - 550 PSI

REQUIRED

GATE TORQUE ABOUT PINTLE, FT-KIPS

PERCENT CLOSED

CLOSING OPERATION

OPEN   100 CLOSED
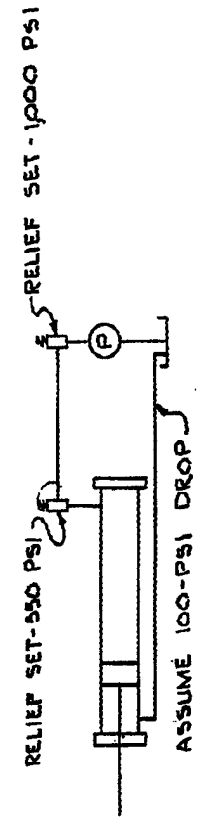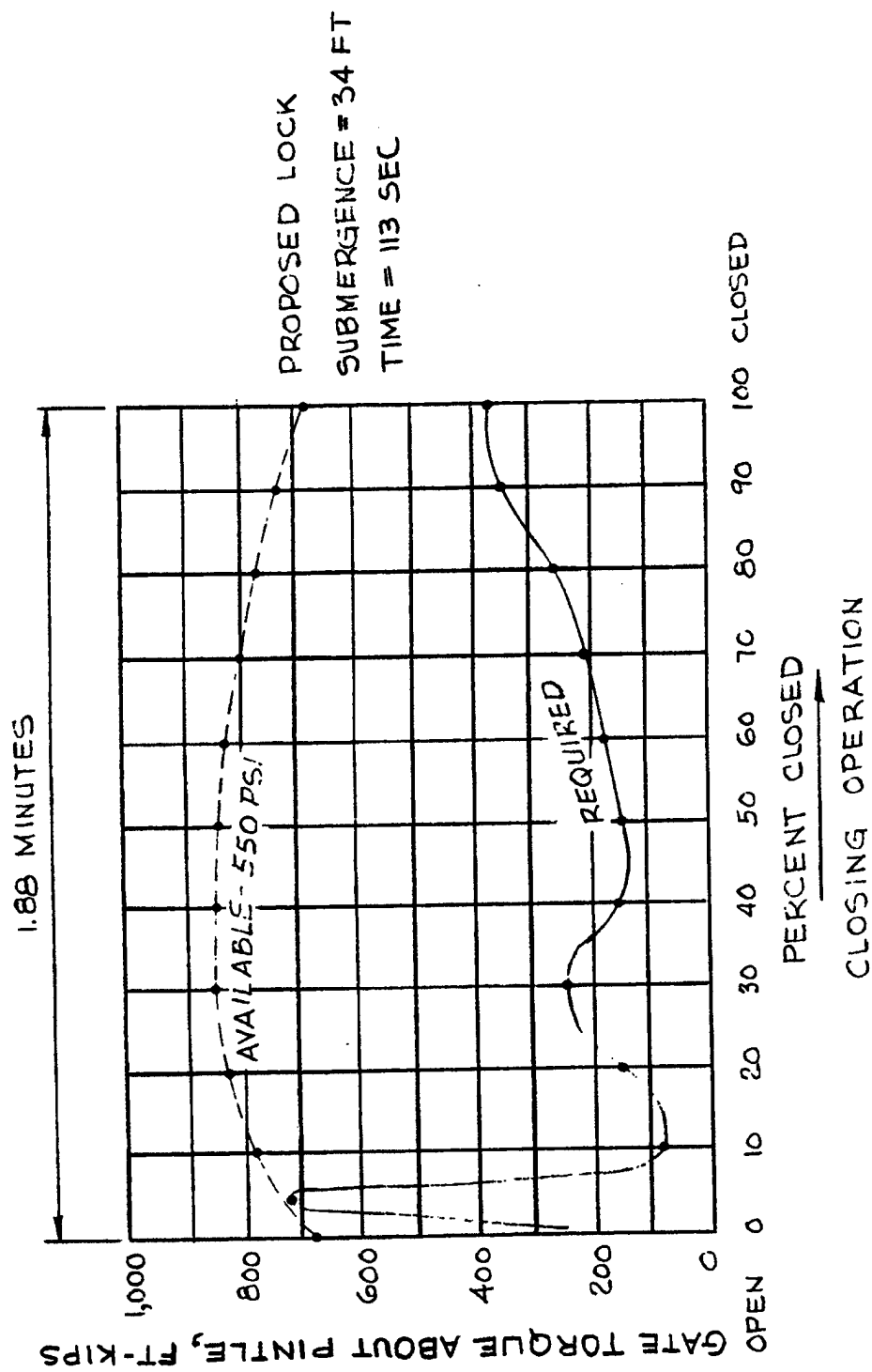
PUMP CAPACITY:

USE 90 SEC OPERATING TIME-OPENING-SEE PLATE **B-87 SHEET 2**

NET AREA - ROD END = 150.83$^{\square''}$

$$GPM = \frac{150.83 \times 12 \times 0.1459 \times 60}{231} = 68.6 \text{ FAST SPEED}$$

$$GPM = 68.6 \times 0.8 = 54.9 \text{ MED SPEED}$$

$$GPM = 68.6 \times 0.3 = 20.6 \text{ SLOW SPEED}$$

USE VARIABLE VOLUME PUMP WITH AT LEAST 4
SETTINGS, "NEUTRAL", "SLOW", "MEDIUM", AND "FAST", WITH
PUMP DELIVERIES AS SHOWN ABOVE.

PLATE B-87
(SHEET 10 OF 10)

DETERMINATION OF LOADS REQUIRED TO RAISE UPSTREAM LEAF (MOVABLE SILL) OF A DOUBLE-LEAF VERTICAL-LIFT GATE:

A. WEIGHT OF UPSTREAM LEAF

B. WEIGHT OF SILT ON UPSTREAM LEAF

C. SLIDING FRICTION OF GATE ON RUBBING STRIPS

D. DOWNWARD HYDROSTATIC LOAD

E. WEIGHT OF RECESS PROTECTION AND TRASH SCREENS LESS WEIGHT OF WATER DISPLACED

F. SIDE SEAL FRICTION

VERTICAL LIFT GATES,
DETERMINATION OF LOADS
FOR UPSTREAM LEAF
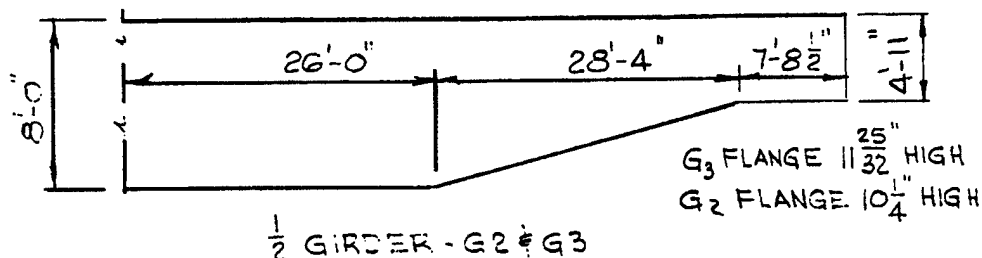PLATE B-88
(SHEET 1 OF 9)

A. WEIGHT OF UPSTREAM GATE

FROM PRELIMINARY CALCULATIONS, WEIGHT OF $14' \times 110'$ GATE WAS ESTIMATED TO BE 185,000 LB

$$\text{WT OF WATER DISPLACED} = \frac{185,000 \times 62.4}{489} = 23,600 \text{ LB}$$

TOTAL WEIGHT TO BE LIFTED = $185,000 - 23,600 = \underline{161,400 \text{ LB}}$

B. WEIGHT OF SILT (IN AIR)

WEIGHT OF SILT = $125 \text{ } ^{LB}\!/_{FT^3}$

$\frac{1}{2}$ GIRDER - G2 & G3

G_3 FLANGE $11\frac{25}{32}"$ HIGH
G_2 FLANGE $10\frac{1}{4}"$ HIGH

WT OF SILT ON GIRDER G1 IS CONSIDERED NEGLIGIBLE

WT OF SILT ON GIRDER G2

$$W_{G2} = \left[2(125)\frac{10.25}{12}\right]\left[(26.0)(8.0) + \left(\frac{8.0 + 4.92}{2}\right)(28.33) + (7.71)(4.92)\right]$$

$$= \left[214\right]\left[(208) + (183) + (38)\right]$$

$$= (214)(429 \text{ }^{\square FT.}) = \underline{91,800 \text{ LB}}$$

$$W_{G3} = \left[\frac{(214)(11.78)}{10.25"}\right](429) = (246)(429) = \underline{105,500 \text{ LB}}$$

$$W_{G1,G2,G3} = 91,800 + 105,500 = \underline{\underline{197,300 \text{ LB}}}$$

C. SLIDING FRICTION OF GATE ON RUBBING STRIPS

SLIDING FRICTION $L_G = P_H A_V C_G H$

P_H = HYDROSTATIC PRESSURE PER FOOT OF HEAD

A_V = AREA OF UPSTREAM SKIN PLATE — SQ FT

C_G = COEF OF FRICTION FOR STEEL ON STEEL, ASSUMED TO BE 0.40

H = SWELL HEAD, ASSUMED TO BE 1.0 FT

$L_G = (62.4)(113.16 \times 13)(0.40)(1.0) = 36{,}718$ LB

D. DOWNWARD HYDROSTATIC LOAD

DOWNWARD LOAD = $L_D = P_H A_T H$

P_H = HYDROSTATIC PRESSURE PER FOOT OF HEAD

A_T = AREA, TOP OF GATE — SQ FT

H = SWELL HEAD, ASSUMED TO BE 1.0 FT

$L_D = (62.4)[(54.71)(8.0)+(6.56)(1.44)+(4.4)(5.0)][2]$

$\quad = (62.4)[437+9.0+22.0][2]$

$\quad = 58{,}400$ LB

E. WT OF RECESS PROTECTION AND TRASH SCREEN MINUS WT OF WATER DISPLACED.

TRASH SCREENS AND RECESS PROTECTION = 18,200 LB *

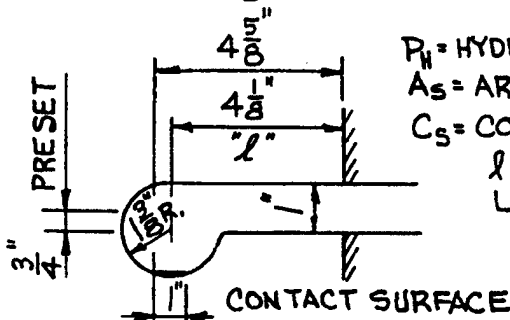WT OF DISPLACEMENT = $\dfrac{18{,}200}{489} \times 62.4 \quad = \quad \underline{2{,}320}$

NET WEIGHT $\quad\quad\quad\quad\quad\quad = 15{,}900$ LB

*ESTIMATE FROM PREVIOUS JOB

F. SIDE SEAL FRICTION

$$L_S = \frac{1}{2} P_H A_S C_S H + P_{PRESET} C_S$$

P_H = HYDROSTATIC PRESSURE PER FOOT OF HEAD.
A_S = AREA OF SEAL SUBJECT TO DIFF HEAD
C_S = COEF OF FRICTION, RUBBER ON STEEL = 1.0
ℓ = LENGTH OF CANTILEVER = $4\frac{1}{8}$"
L = LENGTH OF SEAL
Δ = DEFLECTION (PRESET = $\frac{3}{4}$")
E = MOD ELASTICITY - RUBBER 60 DURO. = 2,000 PSI t = 1"

FORCE DUE TO SEALS ON SIDE (FOR 1 FT)

$$P_{PRESET} = L\left(\frac{3\Delta EI}{\ell^3}\right) = L\left(\frac{3\left(\frac{3}{4}\right)(2,000)\left(\frac{1}{12}\right)(12)(1)^3}{4.125^3}\right) = L(64.2)$$

$$L = (2\ SIDES)(13'\text{-}7") = 2 \times 13.58 = 27.16$$

$$P_{PRESET} = (27.16)(64.2) = \underline{1747}\ LB$$

$$L_S = \frac{1}{2} P_H A_S C_S H + P_{PRESET} C_S \quad A_S = \left(\frac{4.63}{12}\right)(27.16) = 10.5\ ^\square FT$$

$$L_S = \frac{1}{2}(62.4)(10.5)(1.0)(1.0) + (1747)(1.0)$$

$$L_S = 328 + 1,747 = 2,075\ LB \quad (SIDE\ SEALS)$$

FORCE DUE TO SEALS IN RECESS (DISREGARD PRESET)

$$L = 4\left(7'\text{-}4\frac{1}{2}"\right) + 2(5'\text{-}0") = 4(7.38) + 2(5.00) = 39.5\ FT$$

$$A_S = \left(\frac{5.50}{12}\right)(39.5) = 18.1\ ^\square FT$$

$$L_S = \frac{1}{2} P_H A_S C_S H = \left(\frac{1}{2}\right)(62.4)(18.1)(1.0)(1.0) = 565\ LB$$

TOTAL SIDE-SEAL FRICTION
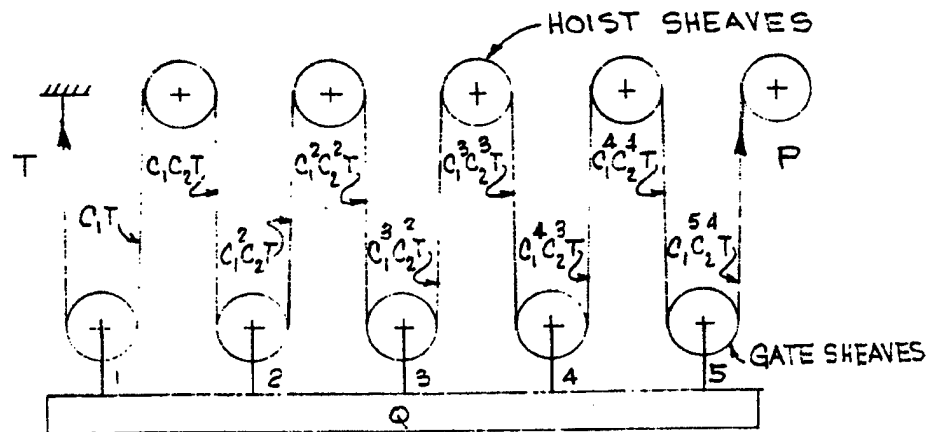
$$L_S = 2,075 + 565 = \underline{2,640\ LB}$$

PLATE B-88
(SHEET 4 OF 9)

HOIST REEVING FOR RAISING UPSTREAM EMERGENCY GATE.

IO PART REEVING

DRUM

UPSTREAM GATE LEAF

FLOW

CROSSOVER IN TUNNEL

SUPPORT ROLLERS

PLATE B-88
(SHEET 5 OF 9)
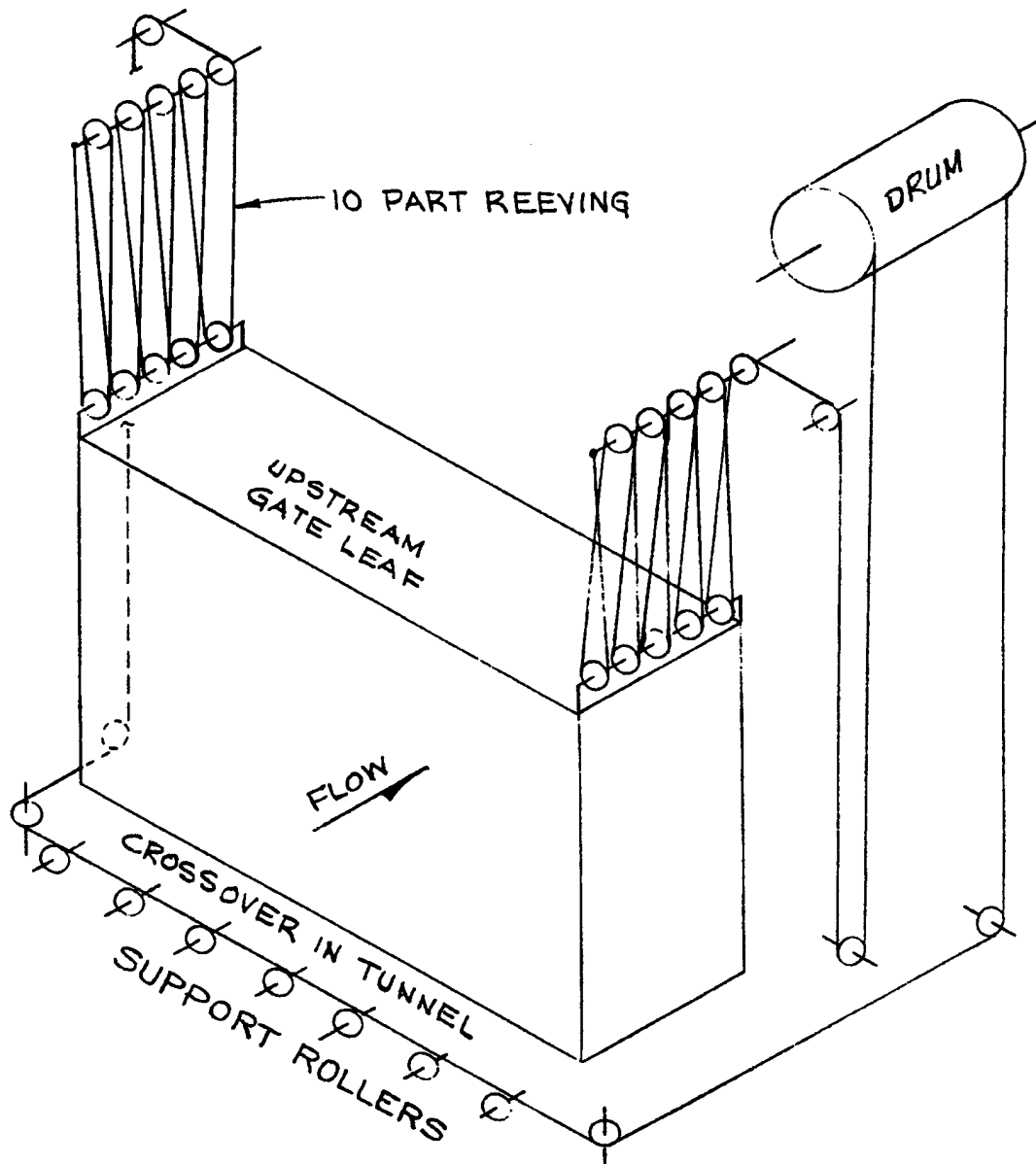
LOAD IN ROPE THROUGH SHEAVES

$C_1 = 1.087$ $C_2 = 1.012$ (SEE PLATE B-89, SHEET 12)

$$Q = T + C_1 T + C_1 C_2 T + C_1^2 C_2 T + C_1^2 C_2^2 T + C_1^3 C_2^2 T + C_1^3 C_2^3 T +$$

$$C_1^4 C_2^3 T + C_1^4 C_2^4 T + C_1^5 C_2^4 T$$

$$= \left[1 + 1.087 + (1.087)(1.012) + (1.087)^2 (1.012) + (1.087)^2 (1.012)^2 \right.$$

$$+ (1.087)^3 (1.012)^2 + (1.087)^3 (1.012)^3 + (1.087)^4 (1.012)^3$$

$$\left. + (1.087)^4 (1.012)^4 + (1.087)^5 (1.012)^4 \right] T$$

$$= \left[1.00 + 1.087 + 1.10 + 1.196 + 1.210 + 1.315 + 1.331 + 1.447 \right.$$

$$\left. + 1.464 + 1.592 \right] T = 12.742 \, T$$

$$T = \frac{Q}{12.742}$$

$$F = C_1^5 C_2^4 T = (1.087)^5 (1.012)^4 \frac{Q}{12.742}$$

$$= (1.512)(1.049) \frac{Q}{12.742} = Q / 8.00$$

DRUM LOAD FROM IDLER SIDE

$$P_{DRUM} = C_5 \, C_3^{*\,5} \, P$$

$$= (1.008)(1.028)^5 \, P$$

$$= \frac{(1.008)(1.148)}{8.00} \, Q$$

$$= \frac{Q}{6.91}$$

REEVING EFF

$$= \frac{6.91 \times 100}{10 \text{ SHEAVES}}$$

$$= 69.1 \%$$

IDLER SIDE
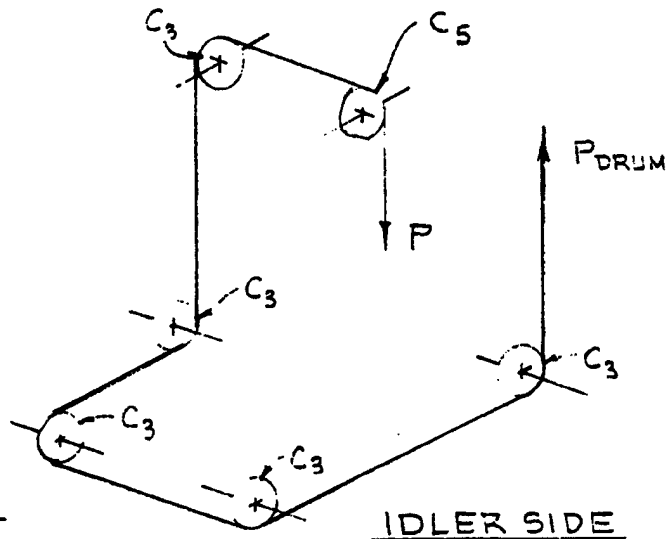
DRUM LOAD FROM MACHINERY SIDE
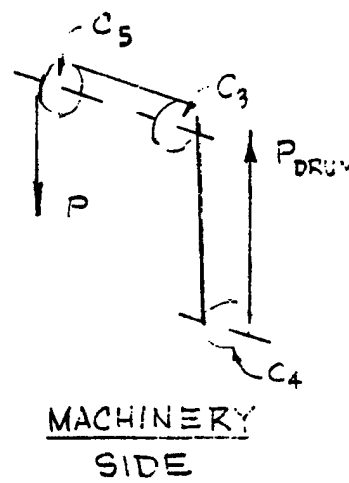
$$P_{DRUM} = C_5 \, C_3^{*} \, C_4^{*} \, P$$

$$= (1.008)(1.028)(1.033) \, \frac{Q}{8.00}$$

$$= \frac{1.070}{8.00} \, Q = \frac{Q}{7.47}$$

REEVING EFF

$$= \frac{7.47 \times 100}{10} = 74.7 \%$$

MACHINERY SIDE

$*C_3, C_4$ AND C_5 SEE PLATE B-89, SHEETS 12, 13, AND 15

PLATE B-88
(SHEET 7 OF 9)

TOTAL LOAD ON HOIST TO RAISE GATE

CONDITION I

DEAD WEIGHT OF GATE IN AIR	185.0 KIPS
SIDE-SEAL PRESET AND TRASH SCREEN WEIGHT	2.6
WEIGHT OF SILT	197.3
TOTAL LOAD	384.9 KIPS

CONDITION II

WEIGHT OF UPSTREAM LEAF IN WATER	161.4 KIPS
WEIGHT OF SILT (IN WATER) $197.3\left(\frac{125-62.4}{125}\right)$	98.8
SLIDING FRICTION	36.7
DOWNWARD HYDROSTATIC LOAD	58.4
WEIGHT OF RECESS PROTECTION AND TRASH SCREENS	15.9
SIDE SEAL FRICTION	2.6
TOTAL LOAD FOR DESIGN	373.8 KIPS

SAY 385.0
(COND. I)

LOAD ON HOIST ROPES AT DRUM

$$P_{DRUM\ IDLER} = \frac{Q}{6.91} = \frac{\frac{385.0}{2}}{6.91} = 27.9\ KIPS$$

$$P_{DRUM\ MACHINERY} = \frac{Q}{7.47} = \frac{\frac{385.0}{2}}{7.47} = 25.8\ KIPS$$

$$P_{DRUM\ TOTAL} = 27.9 + 25.8 = \underline{53.7\ KIPS}\ (DESIGN\ LOAD)$$

PLATE B-88
(SHEET 8 OF 9)

$P_{DRUM\ IDLER}$

$P_{DRUM\ MACHINERY}$

DRUM GEAR

DRUM

PINION

INTERMEDIATE GEAR SET

BRAKE

MOTOR

REDUCER

RIGID COUPLING

FLEXIBLE COUPLING
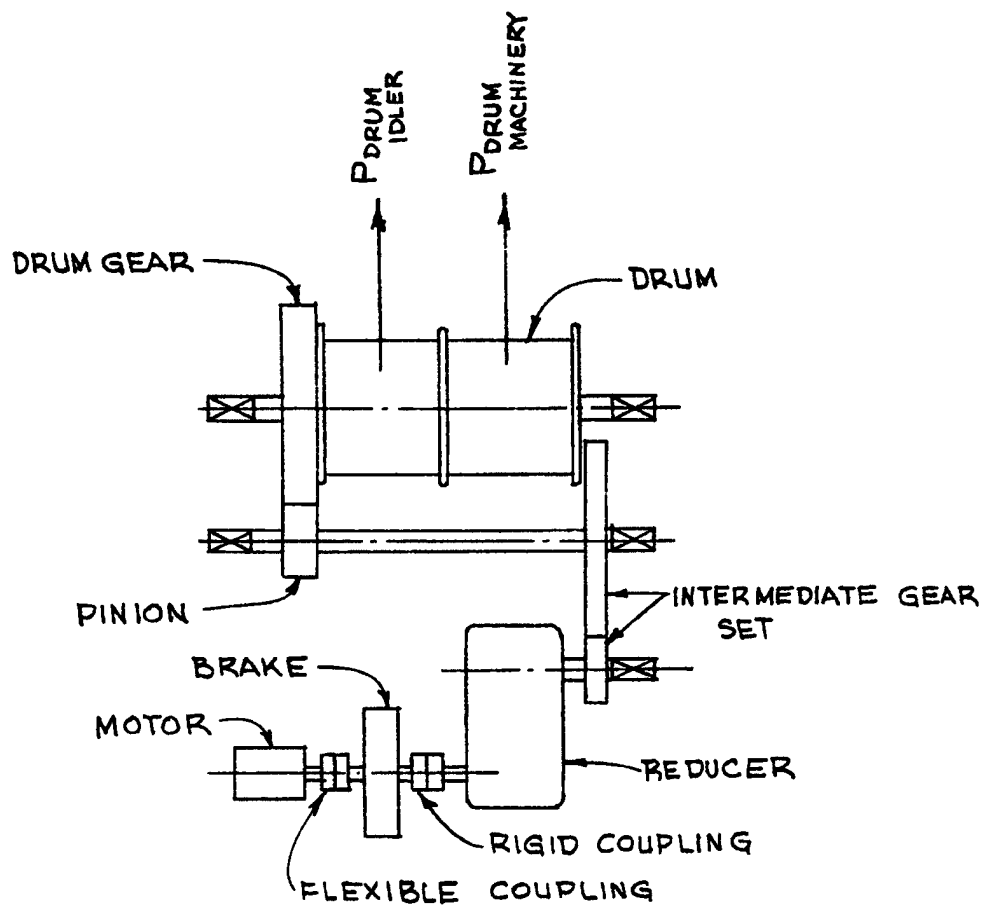
UPSTREAM GATE
HOIST

GENERAL LAYOUT OF
HOIST MACHINERY

DETERMINATION OF LOADS REQUIRED TO RAISE DOWNSTREAM LEAF OF A DOUBLE-LEAF VERTICAL LIFT GATE.

    A. WEIGHT OF DOWNSTREAM LEAF.

    B. WEIGHT OF SILT ON DOWNSTREAM LEAF.

    C. HORIZONTAL FORCE ON GATE LEAF (HYDRAULIC)

    D. VERTICAL FORCE ON GATE LEAF (HYDRAULIC)

    E. GENERAL REEVING LAYOUT FOR DOWNSTREAM GATE

    F. LOADS ON HOIST ROPE AT DRUM

    G. GENERAL LAYOUT OF MACHINE.

VERTICAL LIFT GATES
DETERMINATION OF LOADS
FOR DOWNSTREAM LEAF

PLATE B-89
(SHEET 1 OF 19)

TOP OF WALL - EL 616.0

20-FT DOWNSTREAM LEAF

20'-0"

1'-0"

U.P. EL 602.0

1'-0"

EL 597.0

14-FT UPSTREAM
LEAF (MOVABLE SILL)

20'-0"

1'-0"

EL 584.0

EL 570.0

EL 567.0

EL 564.0

PEDESTALS

EL 557.0

VERTICAL-LIFT GATES
WITH UPSTREAM MOVABLE SILL

PLATE B-89
(SHEET 2 OF 19)
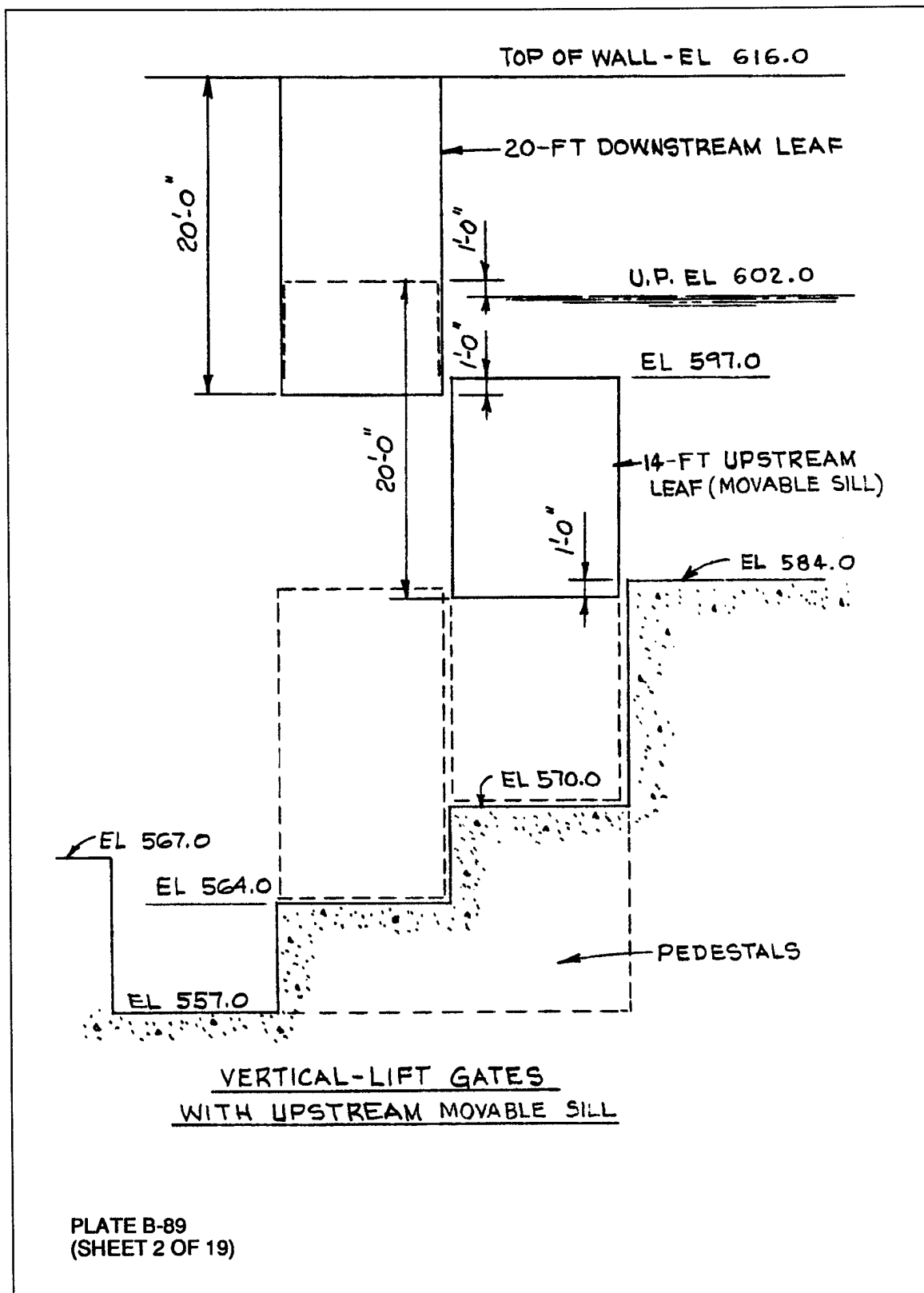
A. WEIGHT OF DOWNSTREAM LEAF

FROM PRELIMINARY CALCULATIONS, WEIGHT OF $20' \times 110'$ GATE WAS ESTIMATED TO BE 467,000 LB

B. WEIGHT OF SILT.
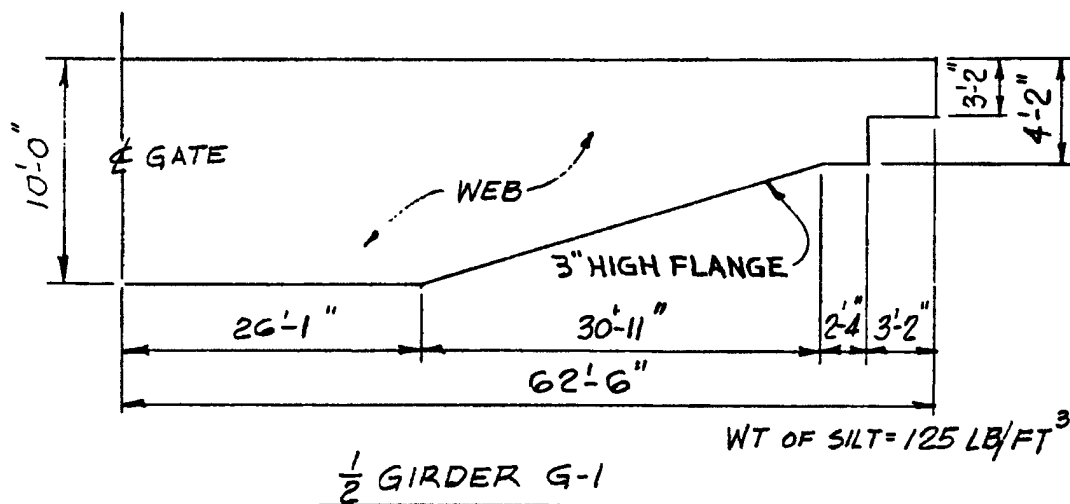
$\frac{1}{2}$ GIRDER G-1

WT OF SILT ON G-1

$$W_{G-1} = 2(125)\left(\frac{3}{12}\right)\left[(26.08)(10.0)+\left(\frac{10.0+4.17}{2}\right)(30.92)+(4.17)(2.33)+(3.17)(3.17)\right]$$

$$= (62.5)\left[260.8+219.07+9.7+10.0\right]$$

$$= 62.5 \times 499.57 = \underline{31,223\ LB}$$

WT OF SILT (CON'TD)
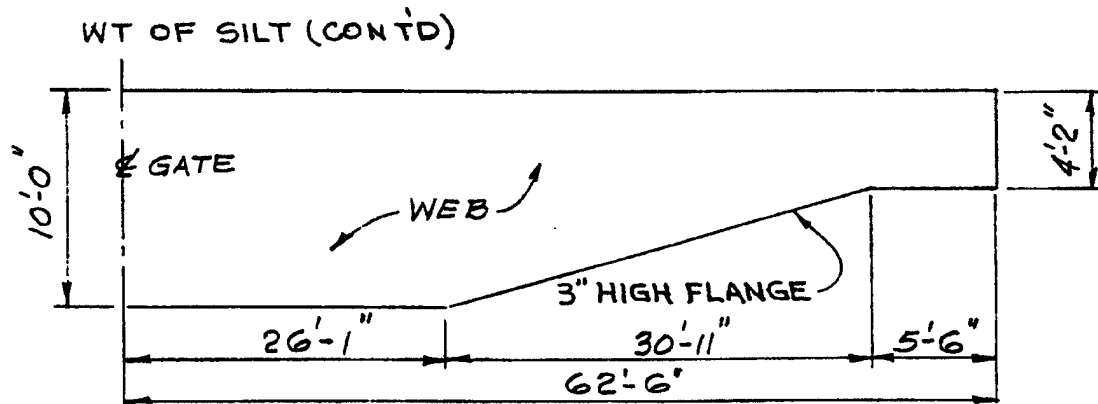
$\frac{1}{2}$ GIRDER G-2, G-3, AND G-4

WT. OF SILT ON G-2, G-3, AND G-4

$$= (3)(2)(125)\left(\frac{3}{12}\right)\left[(26.08)(10.0) + \left(\frac{10.0 + 4.17}{2}\right)(30.92) + (5.50)(4.17)\right]$$

$$= (187.5)\left[260.8 + 219.1 + 22.9\right]$$

$$= 187.5 \times 502.8 = \underline{94,275 \text{ LB}}$$

TOTAL WT OF SILT ON GATE = 31,223 + 94,275 = $\underline{\underline{125.5 \text{ KIPS}}}$

DEAD WT OF DOWNSTREAM LEAF (TOTAL)

$WT = 467.0 + 125.5 = \underline{\underline{593.0 \text{ KIPS}}}$

C. HORIZONTAL FORCE ON GATE LEAF (HYDRAULIC)

USING THE DATA SUPPLIED BY HYDRAULICS BRANCH IN GREEN UP NAVIGATION DAM - ANALYSIS OF HYDRODYNAMIC FORCES ACTING ON EMERGENCY GATE (DATED 7/15/54) AND SUPPLEMENTING THEIR TABLES WITH INTERMEDIATE VALUES, THE HORIZONTAL FORCES ON EMERGENCY GATE VS. FEET GATE RAISED WERE COMPUTED FOR THIS LOCK AND ARE AS FOLLOWS:

AS SOON AS THE EMERGENCY GATE IS LIFTED THE WEIR BECOMES SHARP CRESTED. USE C = 3.5

Q = FLOW IN CFS

L = WIDTH OF WEIR

H = HEIGTH OF WATER ABOVE WEIR

$Q = CL(H)^{\frac{3}{2}}$ (USE END CONTRACTION SUPPRESSED TO GIVE MAX. Q - HANDBOOK OF HYDRAULICS BY KING AND BRATER, PAGE 5-3

$$Q = (3.5)(110)(H)^{\frac{3}{2}} = 385(H)^{\frac{3}{2}}$$

NOTE: SURFACE CONTRACTION
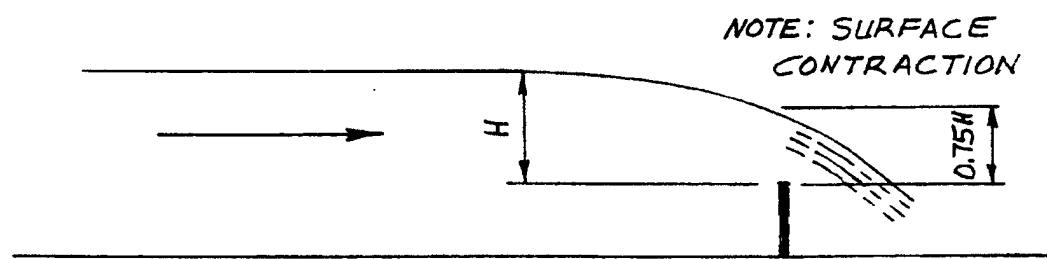
1	2	3	4	5	6
EMERGENCY GATE RAISED (FT)	ELEVATION TOP OF GATE	H $=602-$②	$(H)^{\frac{3}{2}}$	$3.5\,L$ $=3.5\times110$	Q $=3.5L(H)^{\frac{3}{2}}$ $=$④$\times$⑤
0	584	18	76.36	385	29,401
1	585	17	70.09		26,980
2	586	16	64.00		24,640
3	587	15	58.09		22,360
4	588	14	52.38		20,170
5	589	13	46.87		18,040
6	590	12	41.57		16,000
7	591	11	36.50		14,060
8	592	10	31.62		12,170
9	593	9	27.00		10,400
10	594	8	22.63	↓	8,713
11	595	7	18.60		7,160
12	596	6	14.70		5,659
13	597	5	11.20		4,312
14	598	4	8.00		3,080
15	599	3	5.20		2,000
16	600	2	2.83		1,089
17	601	1	1.00		385
18	602	0	0		0

PLATE B-89
(SHEET 6 OF 19)

HORIZONTAL FORCE ON EMERGENCY GATE (CON'T'D)
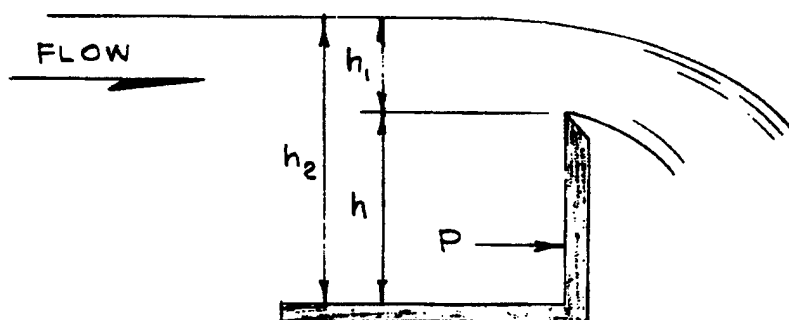
THE FORCE ON THE EMERGENCY GATE WAS COMPUTED USING THE FORMULAS FOR LOADS ON "SHARP-CRESTED WEIRS" FROM ENGINEERING FOR DAMS, VOL.2 (1945) BY HINDS, CREAGER, AND JUSTIN, PAGES 255-257.

$$P = \frac{1}{2} h_2^2 \omega_2 - \frac{q}{g} \omega_2 \left(K \sqrt{2gh_1} - \frac{q}{h_2} \right)$$

P' = TOTAL HORIZONTAL LOAD ON GATE

P = HORIZONTAL LOAD ON 1-FT WIDTH OF GATE

h_2 = UPSTREAM HEAD IN FEET

ω_2 = WEIGHT OF WATER - 62.4 LB/CU FT

q = FLOW IN 1-FT OF CHANNEL (SEE PRECEDING PAGE)

g = ACCELERATION DUE TO GRAVITY - 32.2 FT/SEC/SEC

K = 0.81 (DETERMINED BY EXPERIMENT)

h_1 = UPSTREAM HEAD ABOVE WEIR (SEE H, COL 3 OF PRECEDING PAGE)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
GATE RAISED (FT) h	Q (CFS)	$q = \frac{Q}{110}$ ③	$\frac{w_2 q}{g} = 1.938$③ ④	$h_1 = h_2-h = 18-$① ⑤	$\sqrt{h_1}$ ⑥	$K\sqrt{2g}\sqrt{h_1} = 6.49$⑥ ⑦	h_2 ⑧	$\frac{q}{h_2}$ ③/⑧ ⑨	$K\sqrt{2gh_1} - \frac{q}{h_2}$ ⑦-⑨ ⑩	$\frac{q}{g}w_2(K\sqrt{2gh} - \frac{q}{h_2})$ ④×⑩ ⑪	$\frac{1}{2}h_2^2$ $\frac{⑧^2}{2}$ ⑫	$\frac{1}{2}h_2^2 \times w_2$ ⑫×62.4 ⑬	$P(1\ FT)$ ⑬-⑪ ⑭	P' (TOTAL LOAD) ⑭×110
0	29,400	267	518	18	4.24	27.5	18	14.8	12.7	6,561	162	10,109	3,548	390 KIPS
1	26,980	246	477	17	4.12	26.7		13.7	13.0	6,200			3,909	430
2	24,640	224	434	16	4.00	26.0		12.5	13.5	5,860			4,249	467
3	22,360	204	395	15	3.87	25.2		11.3	13.9	5,490			4,619	508
4	20,170	184	357	14	3.74	24.3		10.2	14.1	5,030			5,079	559
5	18,040	164	318	13	3.61	23.4		9.1	14.3	4,550			5,559	611
6	16,000	145	281	12	3.46	22.5		8.1	14.4	4,040			6,069	667
7	14,060	128	248	11	3.32	21.6		7.1	14.5	3,600			6,509	716
8	12,170	111	215	10	3.16	20.5		6.2	14.3	3,070			7,039	774
9	10,400	95	184	9	3.00	19.5		5.3	14.2	2,610			7,499	825
10	8,713	79	153	8	2.83	18.4		4.4	14.0	2,140			7,969	876
11	7,160	65	126	7	2.65	17.2		3.6	13.6	1,710			8,399	923
12	5,659	51	99	6	2.45	15.9		2.8	13.1	1,300			8,804	968
13	4,320	39	76	5	2.24	14.6		2.2	12.4	942			9,167	1,008
14	3,080	28	54	4	2.00	13.0		1.6	11.4	615			9,494	1,043
15	2,000	18	35	3	1.73	11.2		1.0	10.2	480			9,629	1,060
16	1,089	9.9	19	2	1.41	9.2		0.6	8.6	164			9,945	1,093
17	385	3.5	6.8	1	1.0	6.5		0.2	6.3	43			10,066	1,108
18	0	0	0	0	0	0	0	0	0	0			10,109	1,112

$K = 0.8$

PLATE B-89
(SHEET 8 OF 19)

GATE RAISED ABOVE SILL, FT

HORIZONTAL FORCE ON GATE, KIPS

DOWNPULL FORCE, 100 KIPS

SPRING-TYPE SCALE
TAILWATER EL 484

STRAIN GAGE TAILWATER EL 484

STRAIN GAGE- TAILWATER EL 497

SPRING-TYPE SCALE
TAILWATER EL 497

TAILWATER EL 504.5

UPLIFT FORCE, 100 KIPS

DOWNPULL FORCE, 100 KIPS

UPLIFT FORCE, 100 KIPS

GATE POSITION IN FT. ABOVE SILL ELEVATION

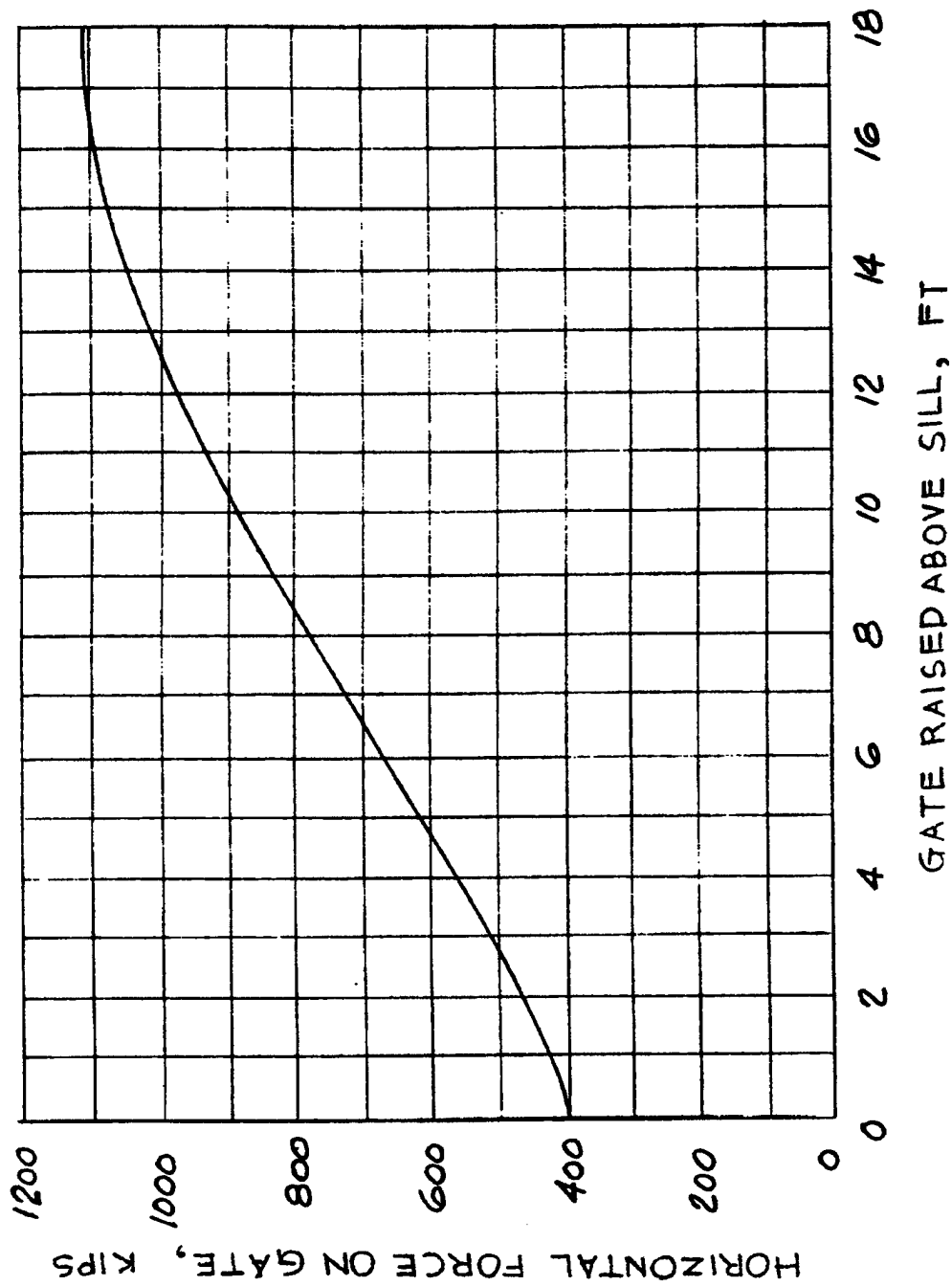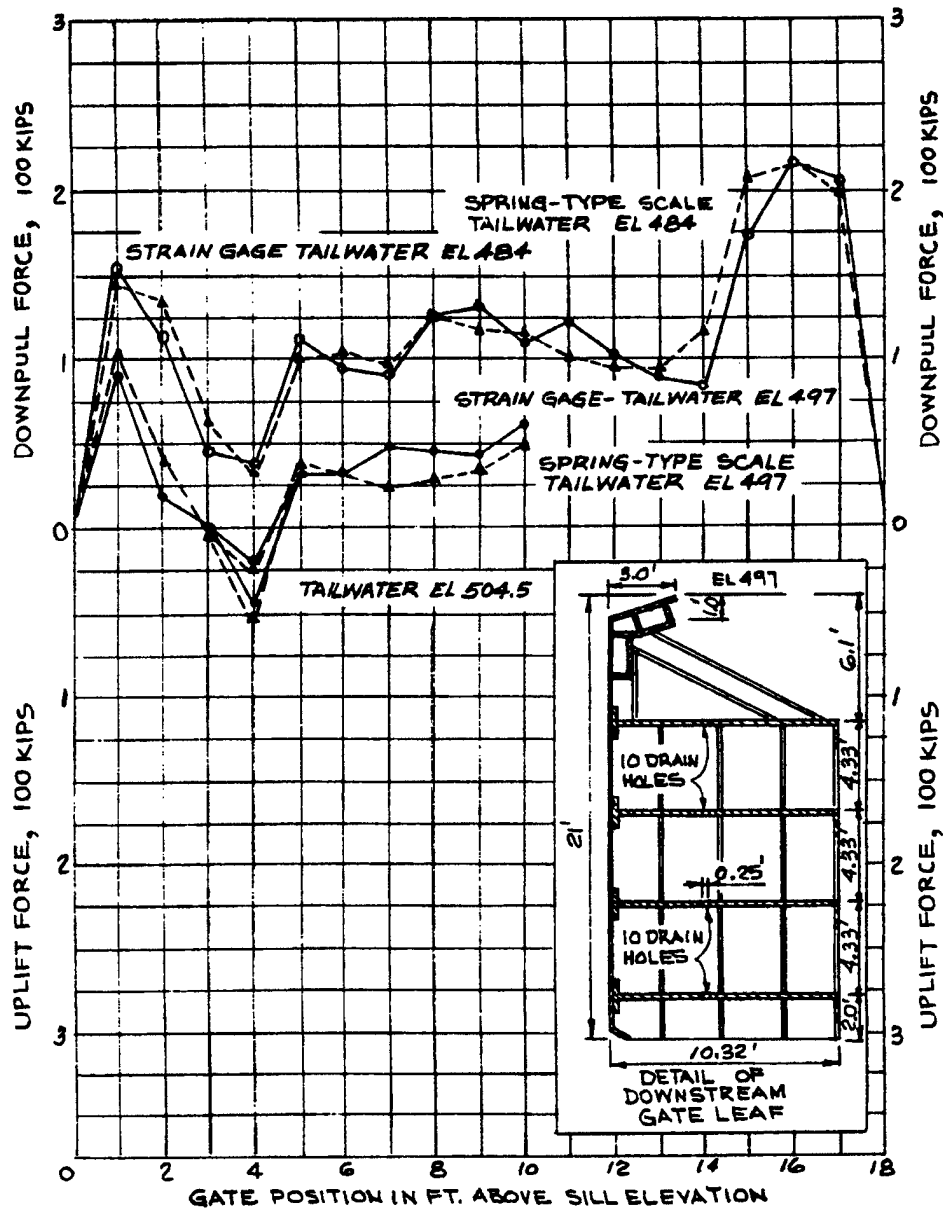EL 497

10 DRAIN HOLES

0.25

10 DRAIN HOLES

10.32'

DETAIL OF
DOWNSTREAM
GATE LEAF

NOTE: OPEN SYMBOLS DESIGNATE LOW
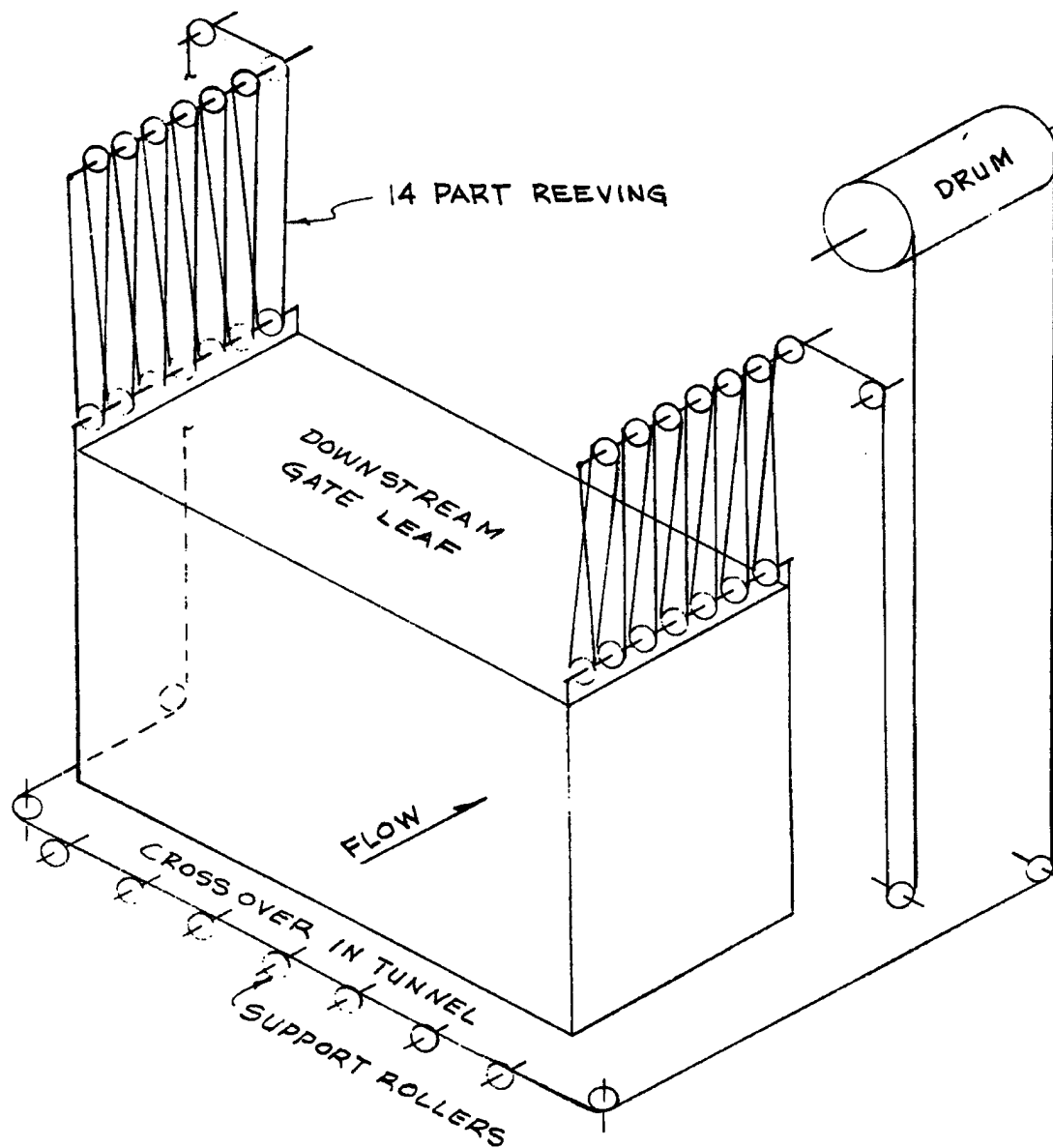TAILWATER. CLOSED SYMBOLS
DESIGNATE HIGH TAILWATER
GATE SILL ELEVATION 497.
DURING OPERATION OF GATE,
UPPER POOL ELEVATION WAS
MAINTAINED AT 515.
AERATION TUBES OPEN DURING TESTS.

EMERGENCY GATE, GREENUP LOCKS,
OHIO RIVER, KENTUCKY.
LOAD ON DOWNSTREAM LEAF
(COMP. FOR RACINE LOCKS)

HYDRAULIC FORCES
TRIANGULAR - SHAPED
GATE CREST - TYPE 9 (FINAL) DESIGN

PLATE B-89
(SHEET 10 OF 19)

E. HOIST REEVING FOR RAISING DOWNSTREAM EMERGENCY GATE.

14 PART REEVING

DRUM

DOWNSTREAM GATE LEAF

FLOW

CROSS OVER IN TUNNEL

SUPPORT ROLLERS

PLATE B-89
(SHEET 11 OF 19)

TENSION RATIOS OF WIRE ROPE SHEAVES

(FROM MACHINE DESIGN BY BLACK AND ADAMS,
THIRD EDITION, PAGES 293
THROUGH 299)

$$C = \frac{D + fd + 2e}{D - fd - 2e'}$$

WHERE

C = TENSION RATIO
D = PITCH DIAMETER OF SHEAVE
f = COEFFICIENT OF FRICTION
d = DIAMETER OF PIN
e AND e' = OFFSET OF ROPE DUE TO BENDING

NOTE: e AND e' ARE ASSUMED TO BE NEGLIGIBLE. DIMENSIONS
AND ARE ESTIMATED AND MUST BE CHECKED.

GATE SHEAVES   TENSION RATIO C_1

D = 36"   d = 11.5"
f (BRONZE ON BRONZE) = 0.133
REF. KENT'S MECH. ENG'R HANDBOOK, 1961, PAGE 7-28

$$C_1 = \frac{36 + (0.133)(11.5)}{36 - (0.133)(11.5)} = \frac{36.0 + 1.53}{36.0 - 1.53} = \frac{37.53}{34.47} = 1.087$$

HOIST SHEAVES   TENSION RATIO C_2

D = 36" $d \cong 14\frac{3}{4}$ 180° TURN
f = 0.0131 (ROLLER BEARING)
REF. KENT'S MECH. ENG'R HANDBOOK, 1961, PAGE 7-31

$$C_2 = \frac{36 + (0.0131)(14.75)}{36 - (0.0131)(14.75)} = \frac{36.0 + 0.193}{36.0 - 0.193} = \frac{36.2}{35.8} = 1.012$$

90° TURN

$$C_3 = \frac{36 + (0.0131)(14.75)(0.707)}{36 - (0.0131)(14.75)(0.707)} = \frac{36 + 0.137}{36 - 0.137} = \frac{36.14}{35.86} = 1.008$$

PLATE B-89
(SHEET 12 OF 19)

TENSION RATIOS OF WIRE ROPE SHEAVES (CONT'D)

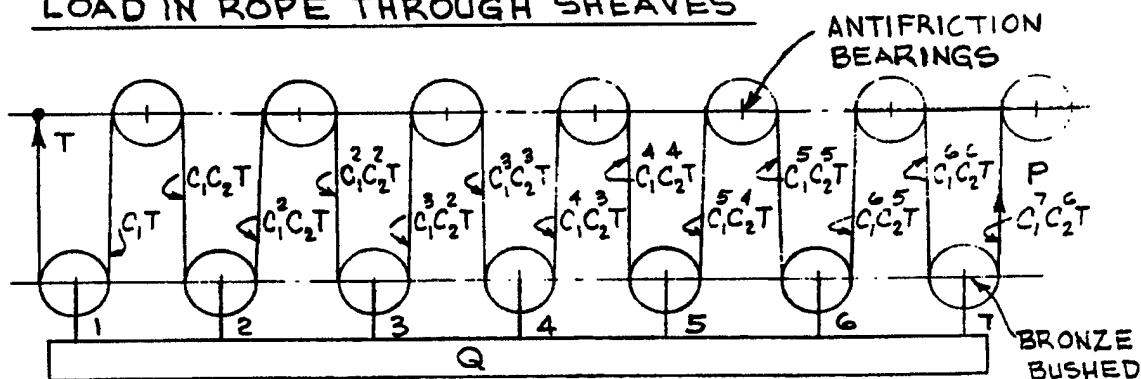### 90° TURN

$$D = 36'' \qquad d = 4.75$$

$$f = 0.133 \quad \text{(BRONZE BUSHED)}$$

$$C_3 = \frac{36.0 + (0.133)(4.75)(0.707)}{36.0 - (0.133)(4.75)(0.707)} = \frac{36.0 + 0.446}{36.0 - 0.446}$$

$$\frac{36.45}{35.55} = \underline{1.025}$$

180° TURN

$$C_4 = \frac{36.0 + (0.133)(4.75)}{36.0 - (0.133)(4.75)} = \frac{36.0 + 0.632}{36.0 - 0.632} = \frac{36.63}{35.37}$$

$$= \underline{1.036}$$

LOAD IN ROPE THROUGH SHEAVES

ANTIFRICTION
BEARINGS

BRONZE
BUSHED

C_1 - LOWER SHEAVES TENSION RATIO COEF.

C_2 - UPPER SHEAVES TENSION RATIO COEF.

ASSUME GATE SHEAVE NO. 4 CARRIES $\frac{1}{7}$ OF THE LOAD.

$$\frac{Q}{7} = C_1^3 C_2^3 T + C_1^4 C_2^3 T$$

$$\frac{Q}{7} = (C_1^3 C_2^3 + C_1^4 C_2^3) T$$

$$T = \frac{Q}{7(C_1^3 C_2^3 + C_1^4 C_2^3)}$$

$$= \frac{Q}{7[(1.087)^3 (1.012)^3 + (1.087)^4 (1.012)^3]}$$

$$= \frac{Q}{7[(1.285)(1.036) + (1.397)(1.036)]}$$

$$= \frac{Q}{7[(1.331) + (1.446)]} = \frac{Q}{7(2.777)}$$

$$= \frac{Q}{19.4}$$

LOAD IN ROPE THROUGH SHEAVES (CONT'D)

$$P = C_1^7 C_2^6 \, 7 \, T = (1.087)^7 (1.012)^6 \, \frac{Q}{19.4}$$

$$P = (1.793)(1.074) \, \frac{Q}{19.4} = \frac{Q}{10.1}$$

DRUM LOAD FROM IDLER SIDE

$$P_{DRUM} = C_5 \, C_3^5 \, P$$

$$= (1.008)(1.028)^5 \, P$$

$$P_{DRUM} = \frac{(1.008)(1.148) \, Q}{10.1}$$

$$P_{DRUM} = \frac{Q}{8.72}$$

$$\text{REEVING EFF.} = \frac{8.72 \times 100}{14}$$

$$= 62.2\%$$

IDLER SIDE
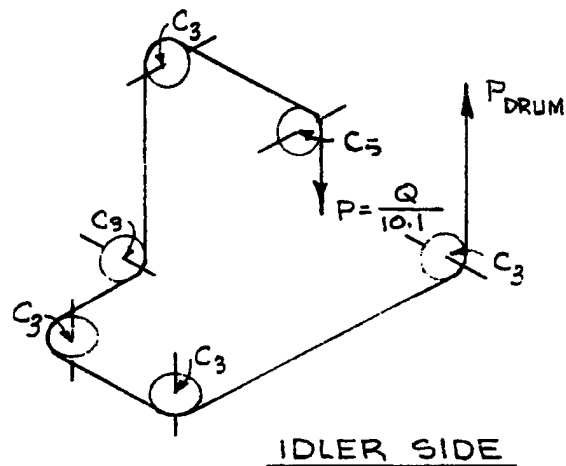
DRUM LOAD FROM MACHINERY SIDE

$$P_{DRUM} = C_2 \, C_3 \, C_4 \, P$$

$$= (1.008)(1.028)(1.033) \, \frac{Q}{10.1}$$

$$= \frac{1.070}{10.1} \, Q$$

$$P_{DRUM} = \frac{Q}{9.44}$$

$$\text{REEVING EFF.} = \frac{9.44 \times 100}{14.0} = 67.4\%$$

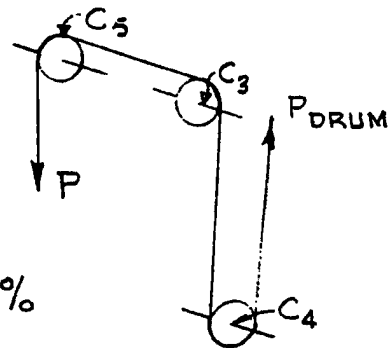| ① FT ABOVE SILL	② Wт/2 & DEAD Wт OF GATE & SILT KIPS	③ P/2 & FORCE NORMAL TO GATE KIPS	④ Ls FRICTION FORCE OF ONE SEAL KIPS	⑤ Lr FRICTION & FORCE OF ROLLERS KIPS	⑥ Fo/2 & DOWN-WARD HYD. FORCE SEE PL.109 KIPS	⑦ LOAD ON ONE GATE SHEAVE ASSY. ②+④+⑤+⑥+Q KIPS	⑧ P DRUM IDLER SIDE ROPE LOAD AT DRUM ⑦÷8.72 KIPS	⑨ P DRUM MACH. SIDE ROPE LOAD AT DRUM ⑦÷9.44 KIPS	⑩ P DRUM TOTAL ⑧+⑨ KIPS
0	247	197	0	9.90	0	207	35.2	32.5	67.7
1		215	1.65	10.75	78	387	44.4	41.0	85.4
2		234	1.74	11.70	57	367	42.1	38.9	81.0
3		254	1.81	12.70	23	335	38.4	35.5	73.9
4		280	1.91	14.01	19	332	38.1	35.2	75.3
5		306	2.01	15.31	57	371	42.5	39.3	81.8
6		334	2.12	16.70	47	363	41.6	38.5	80.1
7		358	2.21	17.90	46	363	41.6	38.5	80.1
8		387	2.32	19.36	63	382	43.8	40.5	84.5
9		413	2.43	20.70	67	387	44.4	41.0	85.4
10		438	2.53	21.90	56	377	43.2	39.9	83.1
11		442	2.62	23.10	62	385	44.2	40.8	85.0
12		484	2.70	24.20	52	376	43.1	39.8	82.9
13		504	2.78	25.20	44	369	42.3	39.1	81.4
14		522	2.85	26.10	39	365	41.9	38.7	80.6
15		530	2.88	26.50	87	415	47.4	43.8	91.2
16		547	2.94	27.40	109	436	50.0	46.2	96.2
17		554	2.97	27.70	104	432	49.5	45.8	95.3
18		556	2.98	27.80	14	342	39.2	36.2	75.4

EXAMPLE COMPUTATION USING GATE RAISED 1 (ONE) FT

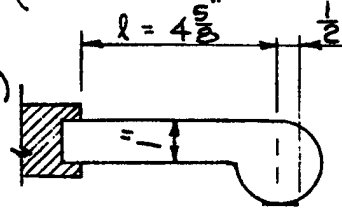COL 2 - DEAD WEIGHT OF ℄ OF GATE (INCLUDING SILT)

$W_T/2 = 573.0/2 = 287$ KIPS

COL 3 - NORMAL FORCE ON ℄ OF GATE
SEE GRAPH "HORIZONTAL FORCES ON EMERGENCY
GATE VS GATE RAISED," PLATE B-89, SHEET 9.

$P'/2 = 430/2 = 215$ KIPS

COL 4 - FRICTION FORCE OF ONE SEAL $\left(\begin{array}{l}\text{FOR LOCATION OF COL.}\\\text{NUMBERS SEE PT. 113}\end{array}\right)$

$C_S = 1.0$ (DESIGN CRITERA)

FORCE DUE TO WATER PRESSURE (P_S)

$$P_S = \frac{(F_N)(A_S)(C_S)}{2(A_P)}$$

F_N = HORIZONTAL FORCE NORMAL TO GATE

A_S = AREA (SQ FT) SEAL SUBJECT TO DIFFERENTIAL HEAD

A_P = AREA (SQ FT) GATE RAISED ABOVE SILL

$$P_S = \frac{(430)(1.0)(5\frac{1}{8}/12)(1.0)}{(2)(110.5)(1.0)} = 0.830^K$$

FORCE DUE TO PRESET OF $\frac{3}{4}''$ (P_P)

$$P_P = \frac{3 \Delta E I}{\ell^3}(L)(C_3)$$

L = LENGTH OF SEAL COMPRESSED

E = 2000 - ELASTIC MOD. - DUROMETER 60 - (SEE KENT'S
5-68)

t = 1''

$$= \frac{3(0.75)(2000)\left[\frac{1}{12}(12'')(1.0'')^3\right](18')(1.0)}{4.625^3}$$

$$= 0.820^K$$

$$L_S (\text{TOTAL}) = P_S + P_P = 0.830 + 0.820 = 1.65^K$$

COL 5 - ONE HALF FRICTION FORCE OF ROLLERS (L_R)

$$L_R = \frac{F_N}{2}(C_R) \quad \text{WHERE } C_R = 0.05 \text{ (DESIGN CRITERIA)}$$

$$= \frac{430}{2}(0.05) = 10.75^K$$

COL 6 - HYDRAULIC DOWNWARD FORCE ON ONE-HALF GATE - $\left(\frac{F_D}{2}\right)$

SEE GRAPH "FORCE UPLIFT OR DOWNPULL VS GATE POSITION

ABOVE SILL" (PLATE 107) $\qquad \frac{F_D}{2} = \frac{156}{2} = 78^K$

COL 7 - TOTAL LOAD ON ONE GATE SHEAVE ASSEMBLY

$$Q = \frac{W}{2} + L_S + L_R + L_{HYD} = 387^K$$

PLATE B-89
(SHEET 17 OF 19)

TOTAL OF CABLE PULLS ON

DRUM - P_{DRUM} PLUS P_{DRUM}
$_{IDLER}$ $_{MACHINERY}$
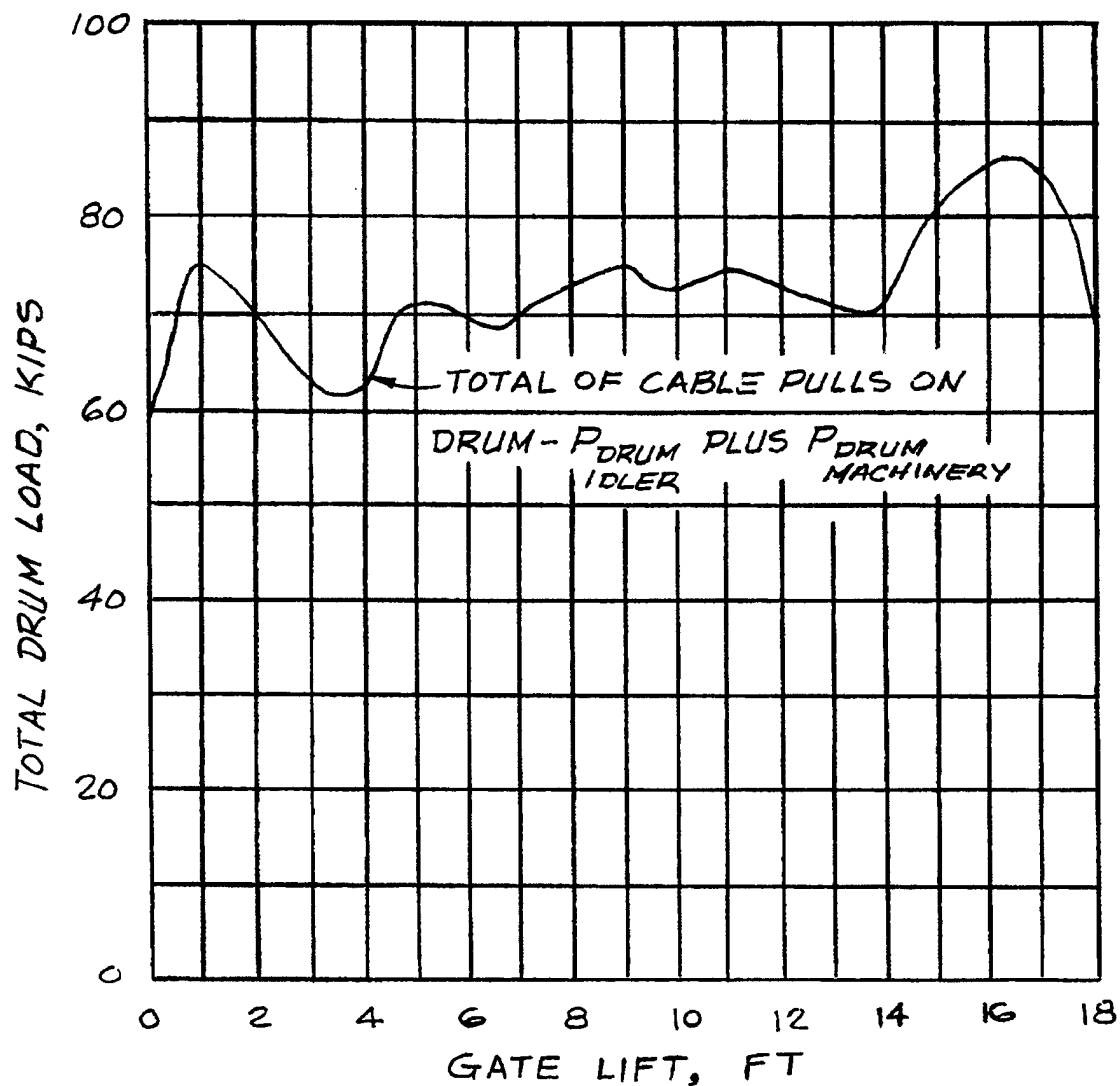
PLATE B-89
(SHEET 18 OF 19)

DOWNSTREAM GATE
GATE LIFT VS. DRUM LOAD
DESIGN LOAD

$P_{DRUM\ IDLER}$

$P_{DRUM\ MACHINE}$

DRUM GEAR

DRUM

PINION GEAR

INTERMEDIATE
GEAR SET

BRAKE

ELECTRIC
MOTOR

REDUCER

RIGID COUPLING

FLEXIBLE COUPLING

DOWNSTREAM GATE
HOIST
GENERAL LAYOUT OF HOIST MACHINE
PLATE B-89
(SHEET 19 OF 19)
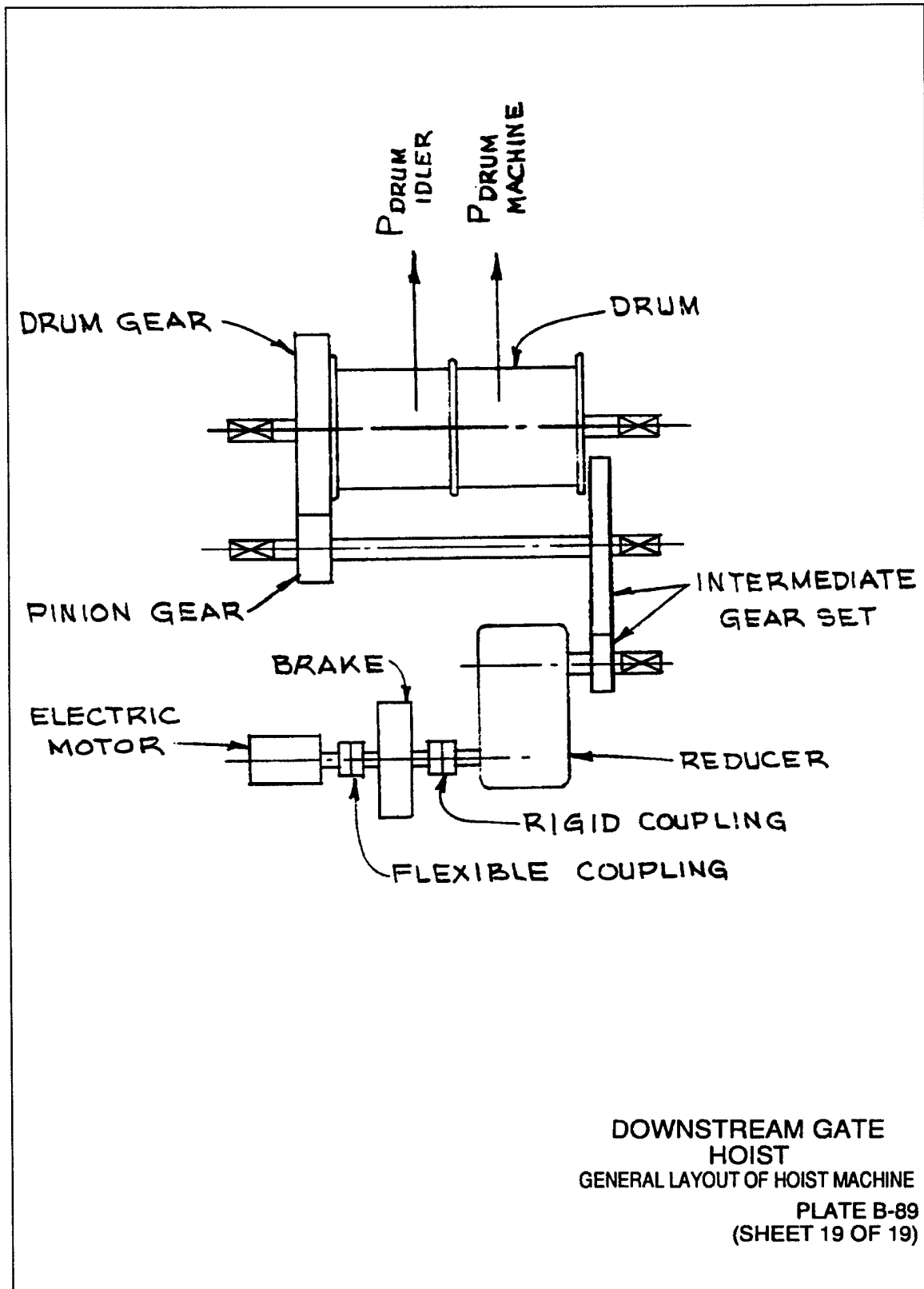
GATE WHEELS (CROWNED TREAD)

LOAD ON WHEEL - MAXIMUM WHEEL LOAD FOR THE FOLLOWING
EXAMPLE IS 337.5 KIPS (WHEEL LOADS ARE DETERMINED
BY THE STRUCTURAL DESIGNER)

WHEEL - ASSUME THE DIAMETER OF TREAD TO BE 36"
WIDTH OF TREAD:

$$WIDTH = \frac{LOAD}{800 \times DIAM \ (INCHES)} = \frac{337.5 \times 1000}{800 \times 36}$$

$$= 11.75" \ USE \ 12"$$

SEE ROARK, "FORMULAS FOR STRESS AND STRAIN,
2ND EDITION " PAGE 292, PARAGRAPH 2, WHERE
MATERIAL IS EQUAL TO" TOOL STEEL," LOADING IS
"SLOW MOTION," AND TYPE OF LOADING IS "CYLINDRICAL
ROLLER ON FLAT PLATE".

COMPRESSIVE STRESS AT POINT OF CONTACT.

ASSUME THE SURFACE OF THE WHEEL IS TO BE MADE
OF WELD DEPOSIT OF E410 OR ER420 ELECTRODES.
THESE ELECTRODES ARE 12% CHROMIUM AND GIVE GOOD
RESISTANCE TO CORROSION, EROSION, AND ABRASION.
SEE WELDING HANDBOOK, SECTION 5, SIXTH EDITION,
PAGE 94-29, BY AMERICAN WELDING SOCIETY, 1973.

THE SURFACE OF THE ROLLER SHOULD HAVE A
BRINELL HARDNESS OF APPROXIMATELY 360, WHICH IS
NORMALLY OBTAINED BY AIR HARDENING.

VERTICAL LIFT GATES,
DESIGN OF WHEELS
PLATE B-90
(SHEET 1 OF 8)

THE DISTANCE FROM THE CENTER OF WHEEL, X, THAT
THE REACTION ON THE TRACK WOULD OCCUR FOR MAXIMUM
SLOPE AT VARIOUS CROWN RADII OF WHEEL TREAD.
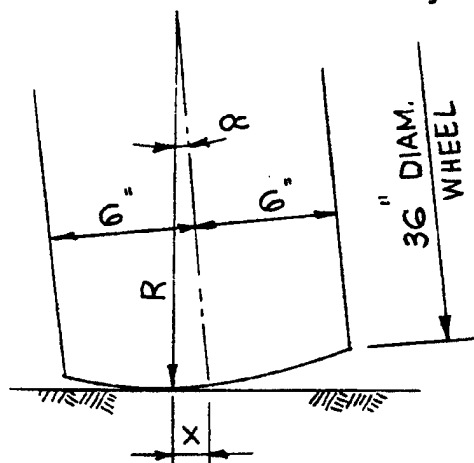
THE SLOPE OF THE GATE UNDER MAXIMUM LOADING
CONDITIONS WAS CALCULATED TO BE AS FOLLOWS:

α (SLOPE) = 0°-12' (AT END OF GATE)

Y MAX = 2.457" (TAN α × GATE LENGTH ÷ 2)

Δ MAX = 1.17" (DEFLECTION - CENTER OF GATE)

R = CROWN RADIUS
WHEEL TREAD

CROWN RADIUS - R	SIN 0°-12'	DISTANCE X (IN.)
20'-0" = 240"	0.00349	0.838
30'-0" = 360"		1.257
40'-0" = 480"		1.675
50'-0" = 600"		2.090
60'-0" = 720"		2.520
70'-0" = 840"		2.930
80'-0" = 960"		3.350

PLATE B-90
(SHEET 2 OF 8)

DETERMINE COMPRESSIVE STRESS AT CENTER OF
ELLIPTICAL CONTACT SURFACE OF GATE WHEEL RUNNING
ON A FLAT PLATE TRACK.

A COMPUTER PROGRAM MAY BE USED TO RAPIDLY
COMPUTE THE MAJOR AXIS OF ELLIPSE, MINOR AXIS OF
ELLIPSE, MAXIMUM COMPRESSIVE STRESS, AND TOTAL
DEFLECTION OF BOTH BODIES.

THE PROGRAM SHOULD BE WRITTEN USING FORMULA'S
WHICH ARE TAKEN FROM ROARK, FORMULAS FOR STRESS
AND STRAIN, 1965 EDITION, PAGE 321, CASE NO. 8, "GENERAL
CASE OF TWO BODIES IN CONTACT."

THE PROGRAM SHOULD ASSUME, FOR THIS PROBLEM,
A MODULUS OF ELASTICITY FOR BOTH WHEEL AND FLAT
PLATE TRACK TO BE 30×10^6 PSI AND POISSON'S RATIO FOR
BOTH BODIES TO BE 0.26.

THE COMPUTER READOUT WOULD BE AS FOLLOWS:

WHEEL DIAM IN.	CROWN RADIUS FT	MAX. COMP STRESS K P S I *	MAJ AXIS ELLIPSE IN.	MIN AXIS ELLIPSE IN.	TOTAL DEFLECTION IN.
36.00	20.00	184	4.34	0.80	0.0142
	30.00	164	5.30	0.73	0.0131
	40.00	158	5.86	0.69	0.0122
	50.00	154	6.30	0.66	0.0116
	60.00	146	6.84	0.64	0.0111
	70.00	142	7.27	0.62	0.0107
	80.00	139	7.62	0.60	0.0104

* MAXIMUM WHEEL REACTION = 337.5 KIPS

PLATE B-90
(SHEET 3 OF 8)

SAMPLE COMPUTATION USING 36-IN. DIAMETER WHEEL, 20 FT
CROWN RADIUS, AND 337.5 KIPS WHEEL LOAD (USING
FORMULAS FROM ROARK)

$R_2' = 240''$ (CROWN)
$R_2 = 18''$ (WHEEL)

R_1' R_1

(R_1' AND R_1 ARE INFINITE)
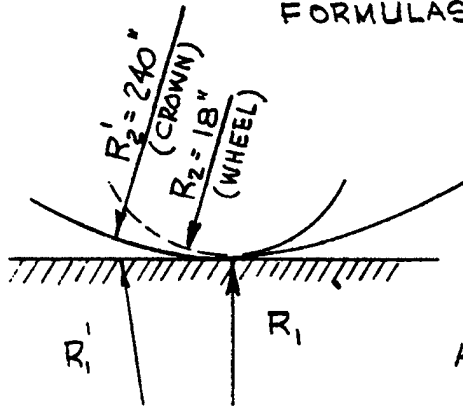
$$\delta = \frac{4}{\frac{1}{INF.} + \frac{1}{R_2} + \frac{1}{INF.} + \frac{1}{R_2'}} = \frac{4}{\frac{1}{18} + \frac{1}{240}}$$

$$= \frac{4}{0.055555 + 0.004167} = \frac{4}{0.0597216}$$

$$= 66.9774$$

$$k = \frac{8}{3} \frac{E_1 E_2}{E_2(1 - V_1^2) + E_1(1 - V_1^2)}$$

$$E_1 = E_2 = 30 \times 10^6 \qquad V = 0.26$$

$$k = 2.66667 \frac{(30 \times 10^6)(30 \times 10^6)}{[30 \times 10^6 (1 - 0.26^2)] + [30 \times 10^6 (1 - 0.26^2)]}$$

$$= 2.66667 \frac{9 \times 10^{14}}{5.5944 \times 10^7} = 2.66667 (1.60875 \times 10^7)$$

$$= 4.29 \times 10^7$$

$$\theta = ARC\ COS\frac{1}{4}\delta\sqrt{\left(\frac{1}{R_1} - \frac{1}{R_1'}\right)^2 + \left(\frac{1}{R_2} - \frac{1}{R_2'}\right)^2 + 2\left(\frac{1}{R_1} - \frac{1}{R_1'}\right)\left(\frac{1}{R_2} - \frac{1}{R_2'}\right)COS\ 2\phi}$$

$$= ARC\ COS\frac{66.9774}{4}\sqrt{\left(\frac{1}{INF.} - \frac{1}{INF.}\right)^2 + \left(\frac{1}{18} - \frac{1}{240}\right)^2 + 2\left(\frac{1}{INF.} - \frac{1}{INF.}\right)\left(\frac{1}{18} - \frac{1}{240}\right)COS\ 2\phi}$$

$$= ARC\ COS\ 16.74435\sqrt{(0)^2 - (0.055555 - 0.00416)^2 + 0}$$

$$= ARC\ COS\ 16.74435\ (0.0513884)$$

$$= ARC\ COS\ 0.8604653 = 30°\text{-}38'$$

FROM TABLE (ROARK PAGE 321) INTERPOLATE

θ	30°	30°-38'	35°
α	2.731	2.6876	2.397
β	0.493	0.4978	0.530
λ	1.453	1.4656	1.550

SAMPLE COMPUTATION (CON'TD)

$$C = \text{MAJOR AXIS} = \alpha \sqrt[3]{\frac{P\delta}{k}} = 2.6876 \sqrt[3]{\frac{(337,500.0)(66.9774)}{4.29 \times 10^7}}$$

$$= 2.6876 \times 0.8077 = 2.17'' \; (SEMI\text{-}AXIS)$$

$$d = \text{MINOR AXIS} = \beta \sqrt[3]{\frac{P\delta}{k}} = 0.4978 \times 0.8077 = 0.402'' \, (SEMI\text{-}AXIS)$$

S_c = MAX COMPRESSIVE STRESS AT CENTER OF CONTACT

$$= \frac{1.5P}{\pi \, cd} = \frac{(1.5)(337.5)}{(3.1416)(2.17)(0.402)}$$

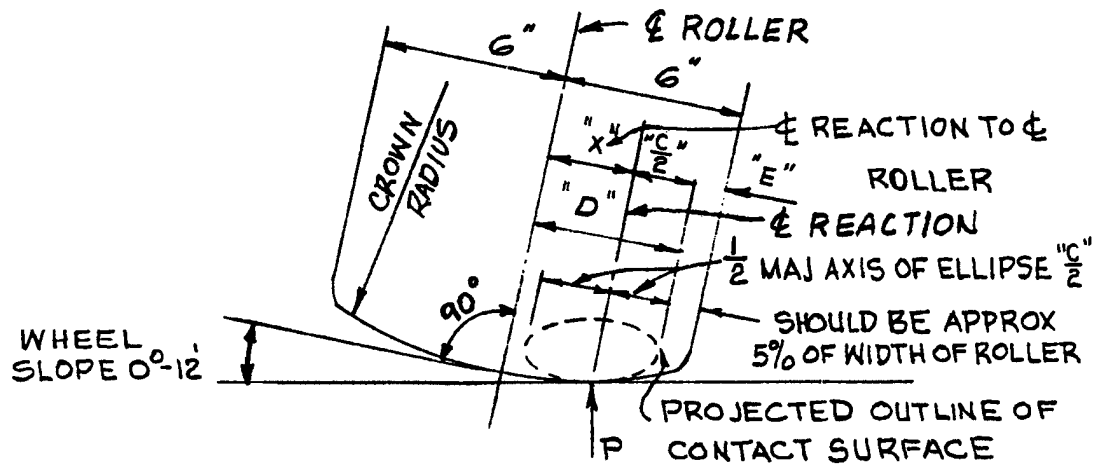$$= \frac{5.0625 \times 10^5}{2.74054} = 184.7 \; ^K/_{SQ\,IN.} \, (COMPARED \; TO \; 184$$
$$K\,SI \; FROM \; THE \; COMPUTER \; PROGRAM, SEE$$
$$PLATE \; B\text{-}90, \; SHEET \; 3)$$

y = COMBINED DEFORMATION OF BOTH BODIES AT CONTACT.

$$= \lambda \sqrt[3]{\frac{P^2}{K^2 \delta}} = 1.4656 \sqrt[3]{\frac{(337,500.0)^2}{(4.29 \times 10^7)^2 (66.9774)}}$$

$$= 1.4656 \, (0.009739)$$

$$y = 0.0142''$$

PLATE B-90
(SHEET 5 OF 8)

THE CROWN RADIUS OF TREAD SHOULD BE AS LARGE AS POSSIBLE YET SELECTED SO THAT THE EDGE OF THE COMPRESSION AREA SHALL FALL WITHIN THE FACE OF THE ROLLER.

"E" = DISTANCE BETWEEN OUTSIDE EDGE OF ROLLER AND OUTSIDE EDGE OF CONTACT SURFACE (ELLIPSE)

$"D" = "x" + \frac{"C"}{2}$ $"E" = \frac{1}{2}$ WIDTH ROLLER MINUS "D"

CROWN RADIUS	"x" - $\mathbb{C}$ REACTION TO $\mathbb{C}$ ROLLER (PL B-90 SHEET 2)	$\frac{1}{2}$ MAJOR AXIS $(\frac{C}{2})$ OF ELLIPSE (PL B-90 SHEET 2)	DISTANCE "D"	EDGE DIST. "E"
20 FT	0.838 IN.	2.17 IN.	3.01 IN.	2.99 IN.
30	1.257	2.65	3.91	2.09
40	1.675	2.93	4.61	1.39
50	2.09	3.15	5.24	0.76
60	2.52	3.42	5.94	0.06
70	2.93	3.64	6.57	-0.57
80	3.35	3.81	7.16	-1.16

THE 50-FOOT CROWN RADIUS SHOULD BE USED SINCE IT IS THE LEAST RADIUS THAT THE ELLIPSE FALLS WITHIN A REASONABLE DISTANCE FROM EDGE OF ROLLER. (SAY 12" WIDE x 5% = 0.6")

WHEEL DESIGN (CON'TD)

THE WHEEL TREAD SHOULD BE DESIGNED WITH A FACTOR OF SAFETY OF 0.5 BASED ON THE YIELD POINT OF THE MATERIAL INVOLVED AND THE MAXIMUM COMPUTED WHEEL LOAD.

CROWN RADIUS	STRESS IN CONTACT AREA OF WHEEL	MINIMUM YIELD POINT OF REQUIRED MATERIAL
20 FT	184 KSI	92.0 KSI
30	164	82.0
40	158	79.0
50	154	77.0 =< 89 KPS
60	146	73.0
70	142	71.0
80	139	69.5

THE ACTUAL YIELD POINT OF THE WELD DEPOSIT OF E410 WELDING ELECTRODES CANNOT BE FOUND BUT CAN BE ESTIMATED FROM ITS ULTIMATE STRENGTH AND BRINELL HARDNESS NUMBER, AND THE KNOWN ULTIMATE STRENGTH, YIELD STRENGTH AT ANOTHER BRINELL NUMBER, AS FOLLOWS:

	BHN	YIELD	ULTIMATE
KNOWN	150 *	35,000 *	70,000 *
UNKNOWN	360 **	X ⊕	178,000 ***

* PROPERTIES OF ELECTRODE USED
** HARDNESS OF DEPOSITED WELD METAL
*** PLATE B-90, SHEET 8.

⊕ $\dfrac{X}{178,000} = \dfrac{35,000}{70,000}$ X = 89,000 PSI

THE STRESS AT 50 - FT CROWN RADIUS FALLS WITHIN THE ALLOWABLE STRESS, SO USE 50 FT
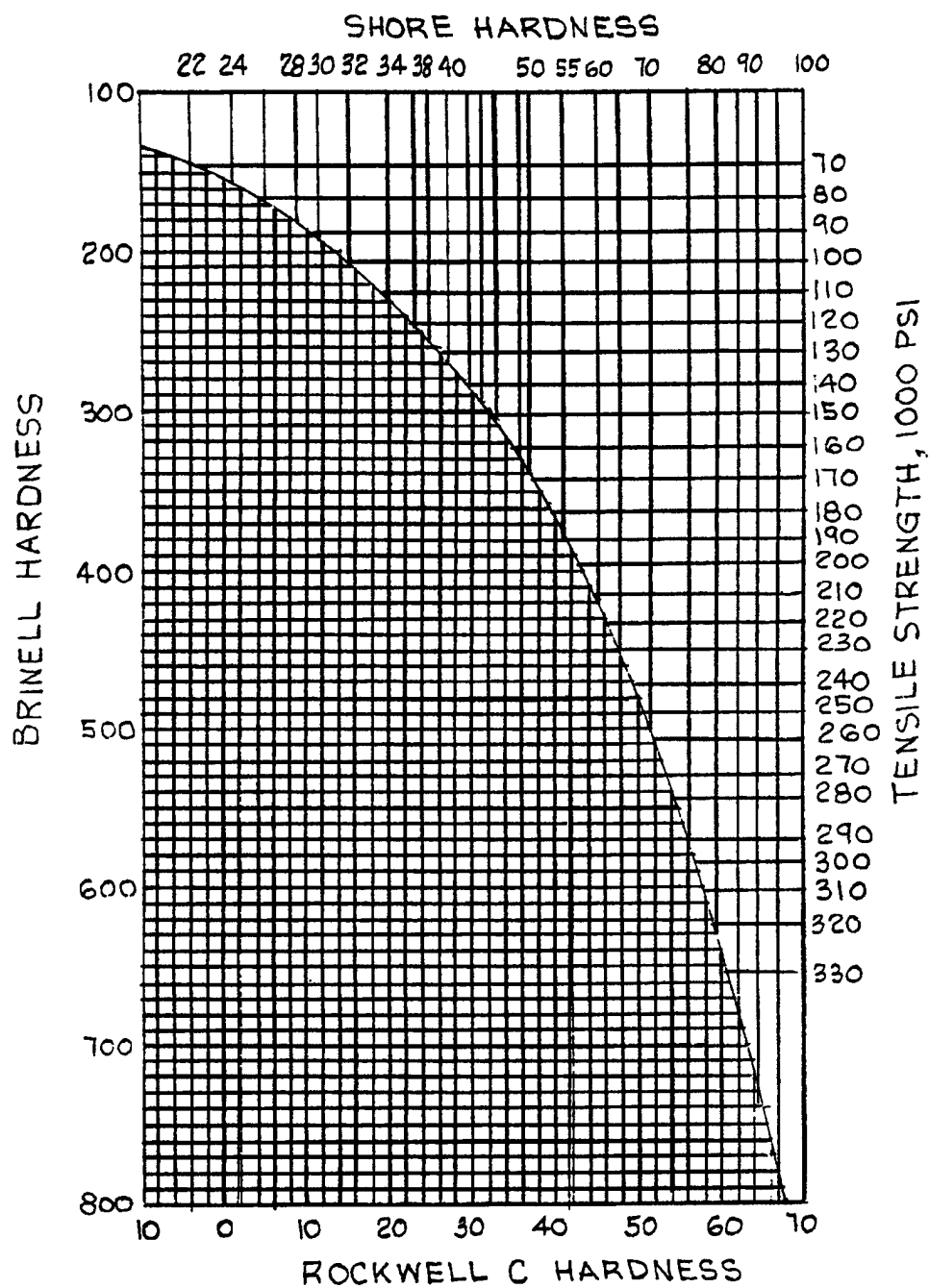
PLATE B-90
(SHEET 7 OF 8)

HARDNESS NUMBERS CONVERSION CHART

PLATE B-90
(SHEET 8 OF 8)

Appendix C
Sample Computations

```
PROGRAM GCOGO -- USAE WATERWAYS EXPERIMENT STATION-- 05/19/83 --  7.490
                    - CORPS SYSTEM PROGRAM U0002 -
COORDINATE GEOMETRY ANALYSIS PROGRAM  733-F3-R0 002    REVISED NOV 1981

DATA INPUT FORM --
  ENTER 0 IF IN A TIMESHARING DATA FILE
     OR 1 IF IN RESPONSE TO QUESTIONS FROM THE TERMINAL
         (GCOGO MAY NOT BE RUN IN BATCH)
  =0


ANGLE DATA CONVENTIONS --
     QUADRANTS   1 = NE   2 = SE   3 = SW   4 = NW
     SIGN = + TO RIGHT, - TO LEFT
     SELECT AN OPTION DEFINING AZIMUTHS ( 1=POSITIVE CLOCKWISE
     FROM SOUTH, 2=POSITIVE CLOCKWISE FROM NORTH)
  =2

EXPONENT OVERFLOW, EXPONENT UNDERFLOW, AND DIVIDE CHECK MESSAGES
PROBABLY INDICATE INCOMPLETE DATA.

ENTER THE FILE DESCRIPTION OF YOUR DATA FILE
 =SAMPLE


COMMENT
20                 EXAMPLE PROBLEM - PINTLE AND RECESS GEOMETRY


REM
COMMENT
40                 PINTLE SET ON PERPENDICULAR FROM CONTACT TO


REM
COMMENT


60                 BISECTOR OF WORK LINE ANGLE. RECESSED WORK LINE


REM
COMMENT
80                 SET SO TIMBERS ARE FLUSHED WITH LOCK CHAMBER FACE


REM
COMMENT
100                QUOIN CONTACT POINT


CLEAR
BETWEEN POINTS    1  AND   999


STORE


REM
COMMENT
170                MITER CONTACT POINT


LOCATE/AZI

    3    8    Y=    61.6667    71    33    54.0
PT.    8    Y=        219.5008    X=        258.5022


AZIMUTH/INT

PT.   14    Y=     200.0000    X=     258.5022


LOCATE/LIN
```

PT. 14 3 15 55.0000
PT. 15 Y= 200.0000 X= 203.5022

LOCATE/LIN

PT. 15 3 16 1.2083
PT. 16 Y= 200.0000 X= 202.2939

REM
COMMENT
260   WORK LINE INTERSECTION

AZIMUTH/INT

PT.   17   Y=   200.7646   X=   202.2939

REM
COMMENT
300   PINTLE LOCATION

AZIMUTH/INT

PT.   1   Y=   201.5913   X=   201.1469

AZIMUTH/INT

PT.   2   Y=   201.1234   X=   201.4978

REM
COMMENT
350   CHECK FOR ANGLE

ANGLE

CLOCKWISE ANGLE FROM   3, AROUND   1, TO   17, =   270   0   0.0

REM
COMMENT
390   CHECK FOR RIGHT ANGLE

ANGLE

CLOCKWISE ANGLE FROM   3, AROUND   2, TO   1, =   89   59   59.9

AZIMUTH/INT

PT.   18   Y=   201.5913   X=   200.0000

REM
COMMENT
450   PINTLE DIST. FROM CONTACT ALONG THRUST LINE

DISTANCE

FROM PT.   2 TO PT.   3 DIST=   1.8723

DISTANCE

FROM PT.   1 TO PT.   18 DIST=   1.1469

DISTANCE

FROM PT.   3 TO PT.   18 DIST=   1.5913

DISTANCE

FROM PT.   1 TO PT.   2 DIST=   0.5849

AZIMUTH/INT

PT.   4   Y=   200.5832   X=   201.5896

REM
COMMENT
550   PINTLE DIST. FROM WORK LINE

DISTANCE

FROM PT.   1 TO PT.   4 DIST=   1.1469

REM
COMMENT
590   PINTLE DIST. FROM CONTACT ALONG WORK LINE

DISTANCE

FROM PT.   3 TO PT.   4 DIST=   1.5913

REM
COMMENT
630   RECESS GEOMETRY

LOCATE/LIN
     3   2   5   -0.2917
PT.   5   Y=   199.8250   X=   199.7666

LOCATE/AZI
     1   6   3.0000   180   0   0.
PT.   6   Y=   198.5913   X=   201.1469

AZIMUTH/INT

PT.   10   Y=   198.5913   X=   203.5022

AZIMUTH/INT

PT.   7   Y=   198.5913   X=   200.6919

LOCATE/LIN
     10   7   19   9.3333
PT.   19   Y=   198.5913   X=   194.1689

AZIMUTH/INT

PT.   20   Y=   207.2887   X=   194.1689

DISTANCE

FROM PT.   7 TO PT.   19 DIST=   2.8102

```
DISTANCE
FROM PT.   7 TO PT.   6  DIST=        0.4550

DISTANCE
FROM PT.   6 TO PT.  10  DIST=        2.3552

DISTANCE
FROM PT.   7 TO PT.  19  DIST=        6.5231

DISTANCE
FROM PT.  19 TO PT.  20  DIST=        8.6974

DISTANCE
FROM PT.   5 TO PT.   7  DIST=        1.5421

STOP
END
DO YOU HAVE MORE DATA TO RUN?
(0 NO, 1 YES )
=0
```

Appendix D
Air Bubbler Gate Recess Flusher

D-1.

High flow air bubblers placed in the gate recess will effectively clear debris and ice. Standard pipe is used for the supply and distribution lines. The supply feed is from the quoin end. Proper spacing and nozzle size will ensure maximum nozzle flow for a given air supply. A typical recess flusher installation is shown in Figure D-1. Air discharge from the orifices is calculated by:

$$Q_o \ (L^{-3}T^{-1}) = \frac{C_d \pi d^2}{4} \ (2\Delta P \ / \ \rho_a)^{1/2}$$

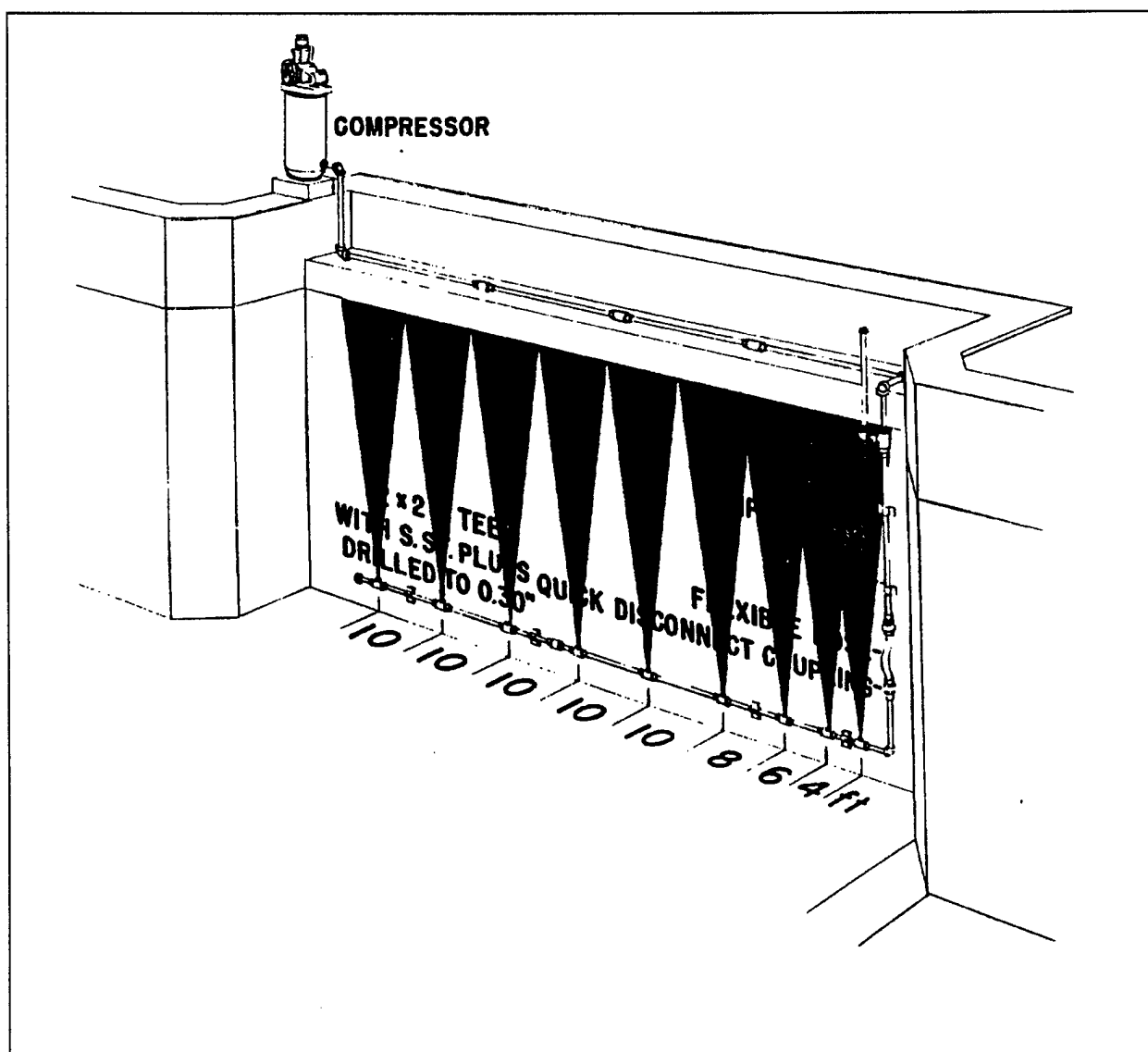C_d = loss coefficient, sharp-edged circular orifice

d = orifice diameter

Figure D-1. Emsworth Lock & Dam, Ohio River, Air Screen Gate Recess Flusher

ΔP = pressure difference between inside and outside of distribution line at the nozzle

ρ_a = mass density of air

The pressure losses due to friction in the lines are calculated using the friction loss equation for turbulent flow:

$$\Delta P_f \ (F \ L^{-2}) = \frac{f \rho_a \ L \ v^2}{2Dg}$$

f = friction factor

L = equivalent length of pipe

v = air velocity

D = pipe diameter

g = gravitational constant

D-2.

The numerical analyses for air discharge rates are determined by an iterative procedure starting with a trial dead-end pressure and the end orifice. Working toward the supply source, the air flow and pressure at each orifice and in the supply line are calculated to obtain a calculated compressor pressure. The trial dead-end pressure is then adjusted and the procedure repeated until the calculated and the true compressor pressures agree. The sum of the nozzle flows gives the required compressor capacity. The initial trial dead-end pressure is taken as:

$$P_d = P_w + 0.25 \ (p_c - p_w)$$

P_c = true compressor pressure

$P_w = \rho_w \ g \ h$

ρ_w = mass density of water

h = submergence depth

Subsequent trial pressures are estimated by:

$$P_{d(new)} = P_w + (P_{d(old)} - P_w) \ (p_c - p_w) \ / \ (p - p_w)$$

p = calculated compressor pressure

$P_{d(new)}$ and $P_{d(old)}$ = new and old trial dead-end pressures

D-3.

Output pressure must be high enough to overcome hydrostatic pressure at the submergence depth, frictional losses in the supply and distribution lines, and still provide a pressure differential at the last orifice to drive the air out at the desired rate. Supply and distribution line diameters should be large enough so that frictional pressure losses along the line are small. A small increase in line diameters often results in significant reduction in frictional losses and results in more uniform discharge rates along the line. Orifice diameter and spacing should be selected to maximize rates. Too large an orifice diameter can result in all the air being discharged at one end. Submergence depth will be dictated by operational limitations but should be lower than the expected depth of trash pile-up. Typical installation depths are 10 to 15 ft.

D-4.

Standard piping techniques can be used for strapping and supply and distribution line make-up. The distribution line can be assembled from standard pipe fittings, e.g., a tee-connection at nozzle locations with a drilled pipe plug used for the nozzle.